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SEDIMENTOLOGY OF WHITE CHANNEL PLACER DEPOSITS, KLONDIKE AREA,
WEST-CENTRAL YUKON

by

STEPHEN ROBERT MORISON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

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ABSTRACT

The White Channel placer deposit in the Klondike area is a Pliocene to early Pleistocene braidplain sequence with tributary alluvial fan and gravity flow deposits.

Lithofacies types range from laminated silt and clay to massive and disorganized boulder gravel. A total of 14 lithofacies types have been identified with cryogenic features such as ice wedge casts found in the upper half of the White Channel section. Dominant lithofacies types include distinctly stratified and crudely stratified gravel which is clast-supported and matrix-filled. An alteration product is recognizable in both White Channel sediments and underlying bedrock.

Proximal White Channel sedimentation is characterized by interbedded channel sequences deposited under fluctuating, high discharge and flood conditions. Medial to distal positions are dominantly sequences of low relief unit barforms and channel lag deposits. Sorting and stratification improves up-section, and facies trends are not consistent. Deposition of White Channel sediments in valley margin positions is characterized by gravelly mass

flows which are interbedded with stratified fluvial sediments.

Placer gold is found in all of the White Channel gravelly facies sampled. Concentration of gold in proximal gravelly facies is due to the development of convergent flow in shallow channels during peak discharge intervals. In medial to distal positions heavy minerals are concentrated in channel sluiceways and aggraded unit bars. Convergent flow in sluiceways between unit bars is not as susceptible to fluctuating discharge levels, and as a result sorting and concentration mechanisms are more efficient up-section. Gold is also concentrated in gravelly mass flow deposits through shear and suspension sorting.

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CHAPTER I. INTRODUCTION

A. GENERAL STATEMENT

Yukon placer deposits are the most economically significant in Canada, and produced over 11,000,000 fine ounces (350,000,000 grams) of gold between 1885 and 1982 (Debicki, 1983). During the 1983 and 1984 mining seasons approximately 75,000 fine ounces of gold (Figure 1) was extracted from Yukon placer deposits (Grapes and Morin, 1985; Emond et al, 1985). Highest production figures are from 1981 when approximately 80,000 fine ounces of gold (Morin and Debicki, 1982; Debicki, 1983) was produced, and contributed up to 5.0 % of total Canadian gold production (Figure 2).

The Klondike area famous for its gold rush of 1896, has consistently been the major producer of Yukon gold. It is located between the Klondike River and Indian River drainage basins (Figure 3), and producing placer mines are found throughout the entire area. The White Channel placer deposit was first discovered in 1897, and is the largest producer of gold in the Klondike area (Gilbert, 1983). To date, there has been little geologic work

done on the White Channel placer deposit. Earlier descriptions of the White Channel sequence (Milner, 1976; Naldrett, 1981), are general and not sedimentologically complete. This project represents the first attempt at a systematic description of White Channel clastic sedimentology.

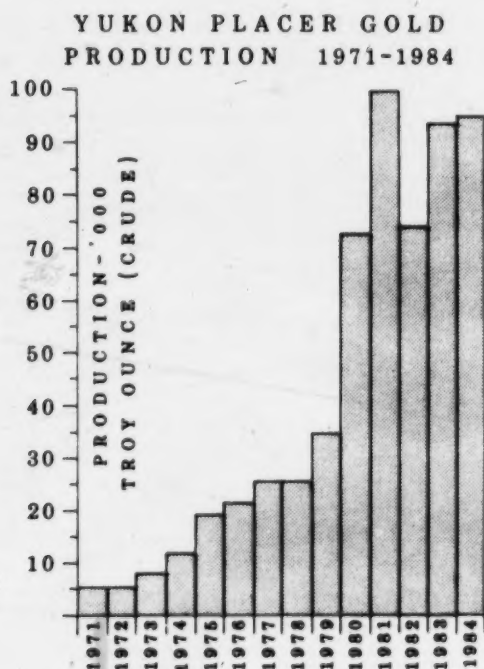


Figure 1: Gold production from Yukon placer deposits from 1971-1984

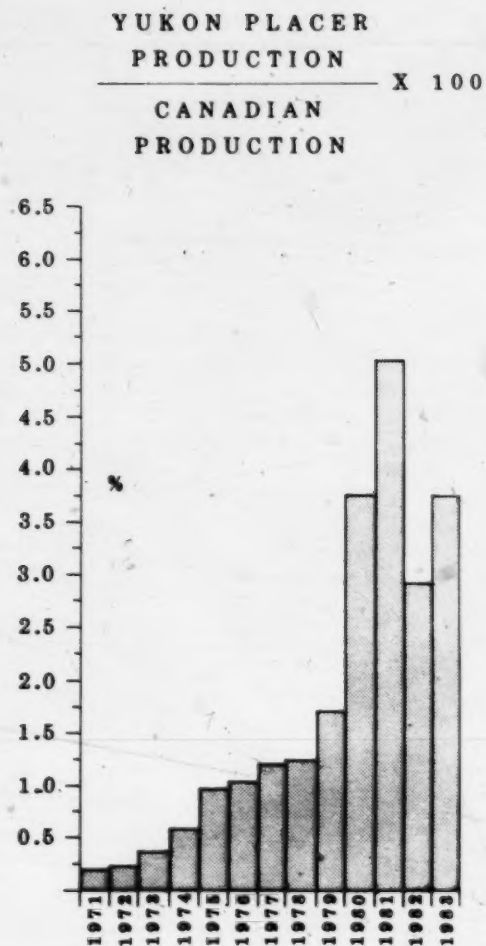


Figure 2: Gold production from Yukon placer deposits as a percentage of total Canadian gold production

(from Emond *et al.*, 1985)

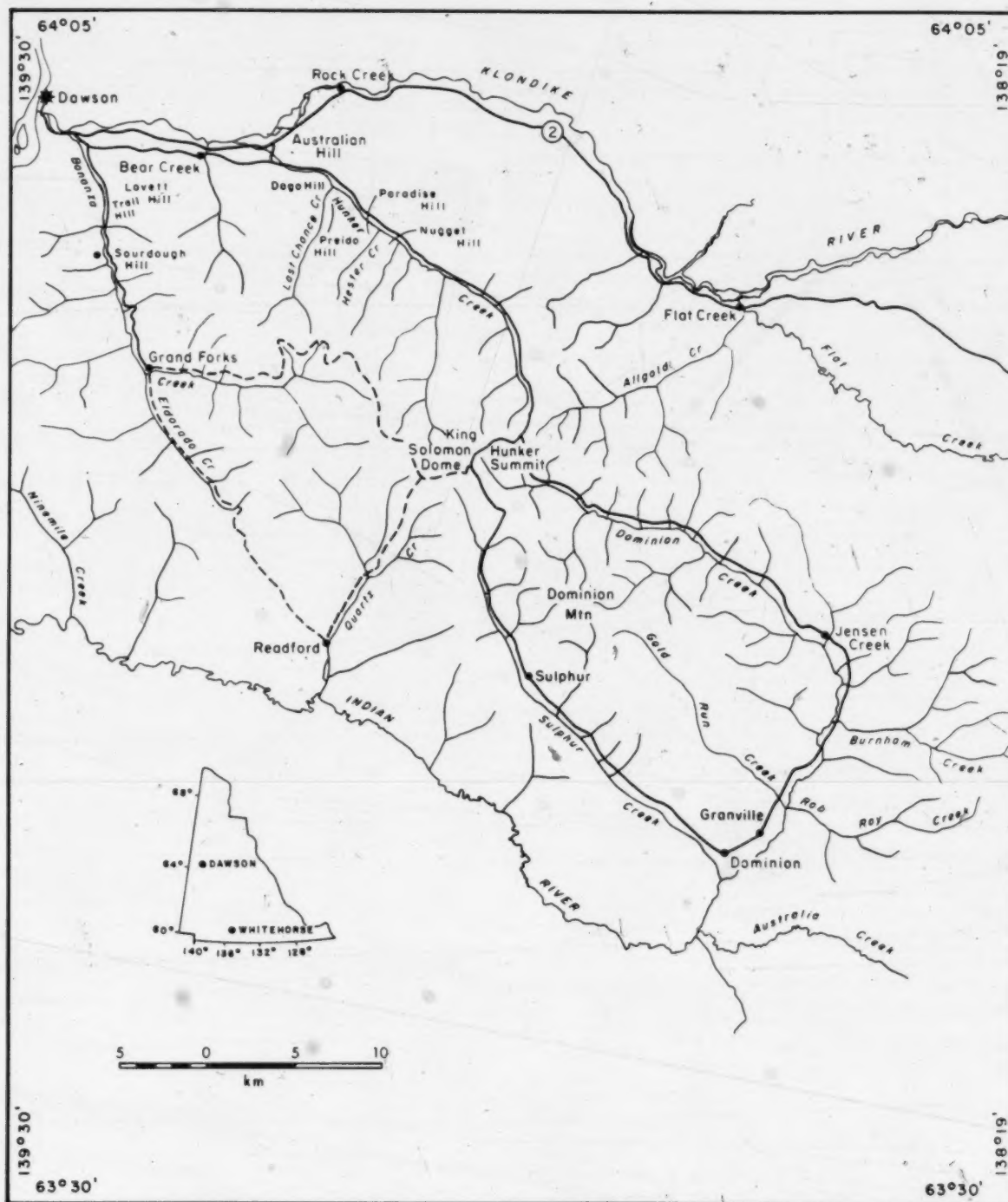


Figure 3: Location map for Klondike placer district.

B. Objectives

The objectives of this work are as follows:

- (1) to systematically describe the sedimentology of the White Channel deposit,
- (2) to develop a lithofacies scheme and lithofacies summary which will characterize the vertical and lateral lithofacies relationships,
- (3) to construct a paleogeographic model,
- (4) to relate the distribution of gold to the above sedimentologic interpretations.

C. REVIEW OF PREVIOUS WORK

Auriferous gravel deposits in the Klondike area were first described by R.G. McConnell (1905, 1907). He divided these deposits into stream gravel, terrace gravel, White Channel gravel, and high level river gravel (Figure 4). The high level river gravel subsequently has been termed Klondike Gravel, and is representative of a pre-Reid glacial advance from the Ogilvie Mountains (Hughes et al., 1972). Since McConnell's descriptions of gold bearing gravel in the Klondike area, most of the geologic work has centred around bedrock mapping and description of mineral occurrences (MacLean, 1914; Rowat, 1916; Bostock, 1942; Green and Roddick, 1962; Gleeson, 1970; Green, 1972; Debicki, 1984 and 1985).

Geomorphology and Quaternary geology of the Klondike area was described by Vernon and Hughes (1966), Hughes (1969), Hughes et al. (1969), Hughes et al. (1972), Hughes and Van Everdingen (1978), Milner (1976), and Naldrett (1981). McConnell (1907) concluded that White Channel gravel was deposited by winding streams with low gradients and, slack currents. Milner (1976), Naldrett (1981) and Tempelman-Kluit (1982) describe the White Channel

sequence as poorly sorted, dominantly massive gravel deposited in a proximal braided environment similar to the "Scott-type" system (Miall, 1978). Dufresne and Morison (1985) recently described the stratigraphy and alteration at Dago Hill in the Hunker Creek drainage. Morison (1985) also described placer deposits in the Clear Creek drainage basin, and noted the similarity of White Channel outcrops in both Clear Creek and Klondike areas.

- a. MUCK.
- b. STREAM GRAVELS.
- c. TERRACE GRAVELS.
- d. WHITE CHANNEL GRAVELS.
- e. HIGH LEVEL RIVER GRAVELS. (KLONDIKE GRAVELS).
- f. KLONDIKE SCHISTS.



Figure 4: Generalized section across the lower part of Bonanza valley (from McConnell, 1907).

D. FIELD METHODOLOGY AND LABORATORY TECHNIQUES

Outcrops of the White Channel placer deposit were mapped and described in Hunker Creek and Bonanza Creek drainage basins (Figure 3). Sections were measured on a bed by bed basis and a total of 116 m vertically and 245 m laterally was described (see Appendix C). The facies scheme was developed and modified during the field season as new sediment types were encountered. Lovett, Trail, and Sourdough Hills provided best examples of White Channel lithofacies types and sequences. Facies sampling in individual beds included a-axis measurement of the 10-largest clasts, a 500 g sample for grain size analysis and a 1-cubic foot bulk sample for heavy mineral and gold content. Random samples were also taken for pollen and pebble counts when appropriate facies types were encountered. At Trail Hill fabric measurements on the a-b plane of elongate pebbles was done to assist with gravelly facies interpretation.

Grain size samples were initially split and sieved through a #10 (U.S. Standard Sieve Number) screen to separate gravel size sediments from sand and mud. Particle size analysis of sand size and muddy fractions was done by wet sieving through #18,

#35, #60, #120, and #230 screens. Muds weights were calculated through subtraction of the total sand and gravel weight from initial sample weight. Grain size fractions were plotted on ternary diagrams as mud-sand-gravel percentages for classification of sediment types (Folk, 1954).

Bulk samples were concentrated by either a hand-rocker or a portable sluice box (Plate 1). Concentrates were then panned, and only "black sand" and gold was retained for heavy mineral identification.



Plate 1. Hand rocker (above) and portable sluice box (below) used to concentrate heavy minerals in bulk samples.



CHAPTER II. GENERAL GEOLOGY

A. REGIONAL SETTING AND BEDROCK GEOLOGY

Yukon is divided into 2 components: (1) northerly autochthonous strata of the North American craton; (2) southwesterly allochthonous fragments accreted to the craton (Tempelman-Kluit, 1981; Monger et al., 1982). The accreted component is divided into the Yukon Cataclastic Complex, Whitehorse Trough, Yukon Crystalline Terrane and Coast Plutonic Complex (Figure 5). The Klondike placer area is in Yukon Cataclastic Complex (Figure 5) which is structurally sheared and metamorphosed terrain. Structural elements include basal Klondike Schist or the Nisutlin Allochthon, sheared ophiolite termed the Anvil Allochthon, and the highest element called the Simpson Allochthon which is composed of sheared plutonic rocks (Tempelman-Kluit, 1981). North of the Klondike area is the major strike-slip Tintina Fault with up to 450 km of Tertiary dextral slip (Tempelman-Kluit, 1981). This feature forms the narrow Tintina Trench graben, which was probably active up to the Pliocene (Tempelman-Kluit, 1981).

Bedrock geology in the Klondike area is

characterized by rock types found in 3 broad time intervals (Debicki 1984, 1985). These include:

- (1) Triassic or older rocks which comprise the majority of the Klondike area, and include plutonic rocks, quartzofeldspathic schistose rocks, carbonaceous rocks, marble, mafic metavolcanic rocks, and mafic schistose rocks.
- (2) Early Cretaceous and/or older rocks which are primarily diabase dykes;
- (3) Late Cretaceous to Early Tertiary rocks which include felsic and intermediate intrusive and felsic volcanic sequences with associated sedimentary rocks.

Despite intensive bedrock exploration, the source rocks responsible for placer gold mineralization in the Klondike area are not known. There appears to be no relationship between bedrock mineral occurrences and the amount of extracted gold from unconsolidated gravel deposits.

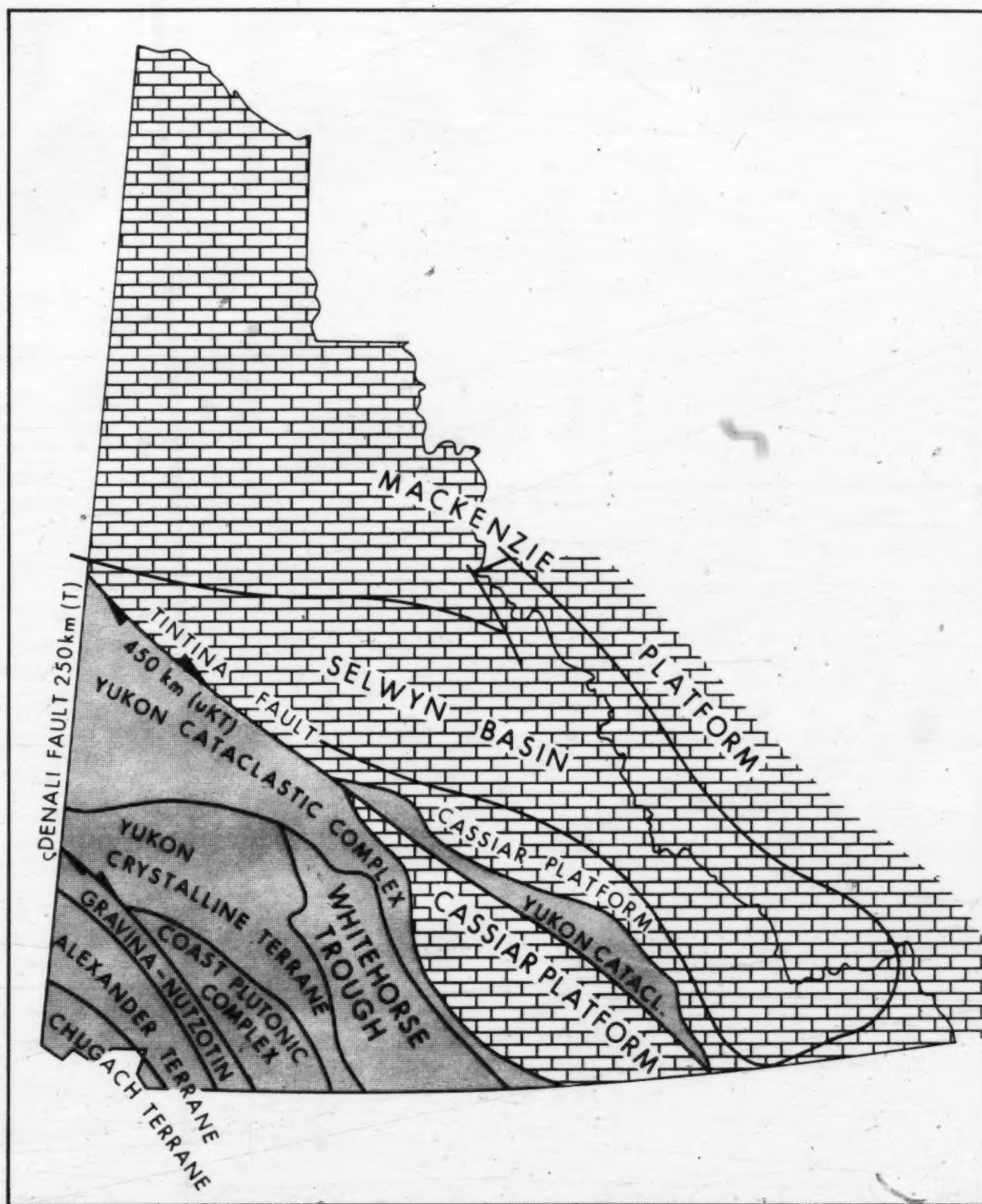


Figure 5: Tectonic Elements of the Yukon (from Tempelman-Kluit 1981).

B. PHYSIOGRAPHY AND GEOMORPHIC HISTORY

The Klondike placer area is in the unglaciated portion of the western Yukon Plateau (Figure 6), or the Klondike Plateau (Bostock, 1948). It is an uplifted erosional surface of Tertiary age characterized by dissected, rolling terrain of accordant ridges (Bostock 1948, 1970; Tempelman-Kluit, 1980). This subdued, mature landscape is the result of extensive subaerial erosion which ended around the Miocene (Tempelman-Kluit, 1980). Drainage patterns during this time were dominantly toward the southwest. Differential uplift and thus initiation of terrain rejuvenation began around the Pliocene (Tempelman-Kluit, 1980), and continued into the Pleistocene (Hughes, 1970). White Channel sedimentation was initiated during a period of tectonic stability (Milner, 1976; Tempelman-Kluit, 1980), and must have continued during differential uplift of the plateau surface. It is likely that uplift in the Swede Dome area (Milner, 1976; Hughes et al., 1972) accelerated the aggradational phase of the White Channel deposit through a rise in local base levels. White Channel aggradation ended in early Pleistocene with the onset of pre-Reid glacial

activity and the deposition of the Klondike gravels. The Klondike gravel sequence represents glaciofluvial sedimentation during a pre-Reid glacial advance from the Ogilvie Mountains (Hughes et al., 1972). Mosquito Creek tephra is found on a terrace level which formed after the deposition of the Klondike gravel unit. The tephra is dated at 1.22 Ma (Naeser et al., 1982), and thus gives a minimum date for pre-Reid glacial activity near the Klondike area. Thus, the White Channel sequence in the Klondike area is defined as a gravelly sequence which was deposited during uplift of the Klondike Plateau in the Pliocene, and ended with the deposition of pre-Reid glaciofluvial sediments. Drainage reversals to the north began with differential uplift of the Yukon Plateau, and were completed with the onset of Pleistocene glaciation (Hughes et al., 1972; Tempelman-Kluit, 1980). Continued uplift during the Pleistocene (Hughes, 1969) resulted in downcutting and incision of drainage systems to their present levels (Hughes et al., 1972). It is believed that at least two periods of extensive downcutting occurred with uplift and before the Reid glacial interval (Hughes et al., 1972). The initial phase of incision ended with the onset of terrace gravel sedimentation and the second

phase ended with deposition of valley-bottom stream deposits.

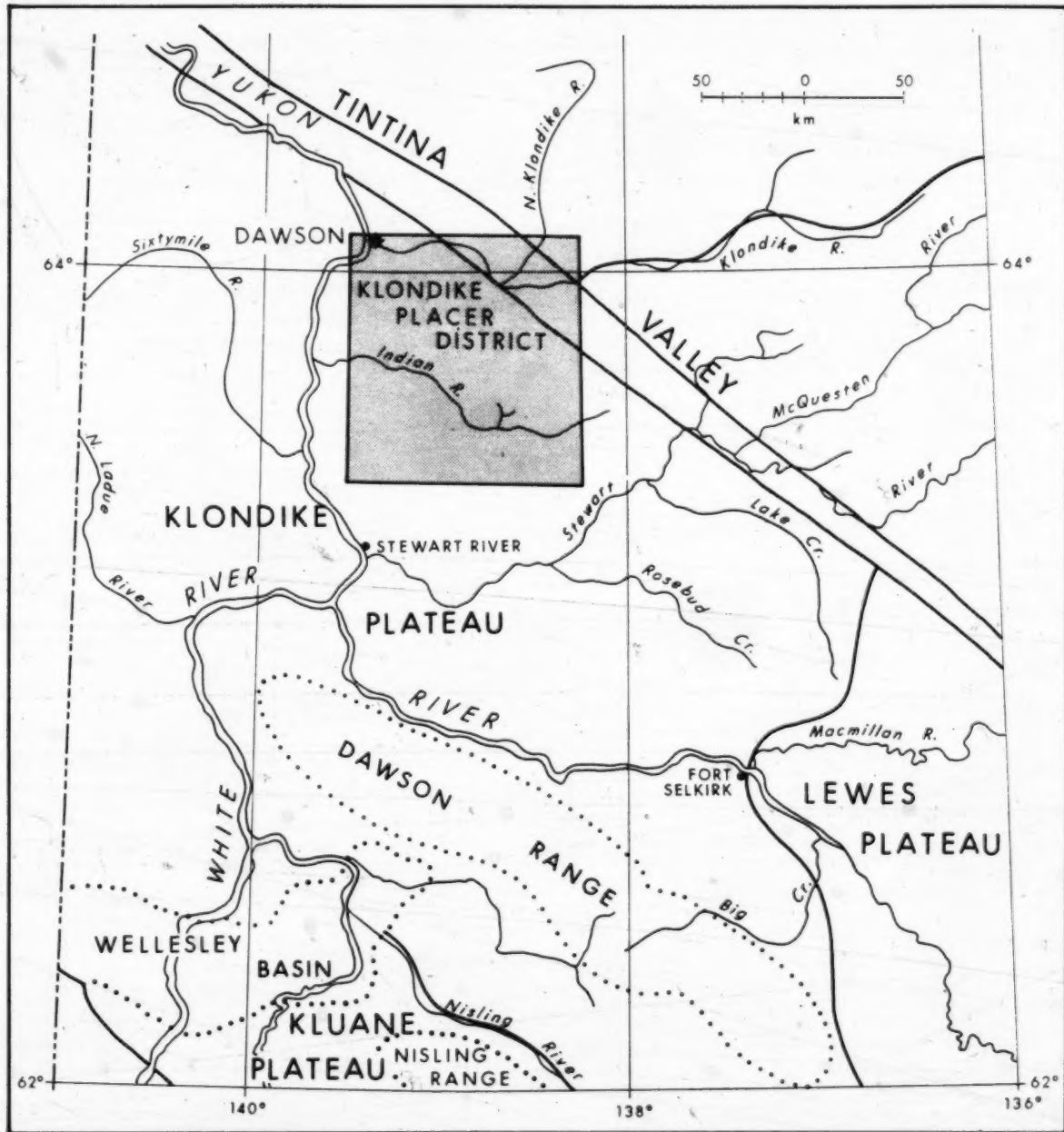


Figure: 6 Physiography of west-central Yukon (from Bostock, 1948).

C. KLONDIKE GRAVEL STRATIGRAPHY

As previously discussed (see Review of Previous Work), McConnell (1905, 1907) divided auriferous gravel deposits in the Klondike area into stream gravel, terrace gravel, White Channel gravel, and high level river gravel or Klondike gravel (Figure 4). The White Channel placer deposit forms terraces approximately 50 to 100 metres above present day stream levels (Plate 2). The maximum measured thickness of the White Channel deposit is 35 m (Plate 3). An additional 10 m upper sequence of interbedded White Channel facies and glaciofluvial, Klondike gravel characterizes bench or terrace stratigraphy at the mouth of Bonanza Creek (Plate 4). The interbedded relationship demonstrates contemporaneous deposition of these two gravelly deposits during the pre-Reid glacial interval (Hughes et al., 1972). McConnell (1907) further subdivided the White Channel deposit into white and yellow gravel units (Figure 7). The terminology for this classification scheme is somewhat confusing. The classification system used by McConnell suggests that the white and yellow gravel units of the White Channel formation are stratigraphically distinct. Exposures show that there

is no distinct break in gravelly sedimentation (Figure 8). This indicates that the yellow gravel unit represents White Channel sedimentation, and is a stained equivalent of the white unit in the White Channel Formation (Plate 5). The yellow staining is probably the result of weathering and supergene migration of iron hydroxides. However, there is evidence of a stratigraphically younger nonglacial gravel unit at Dago Hill (Figure 9). This gravel unit is termed iron-stained fluvial gravel, and directly overlies White Channel silty clay overbank sediment (Dufresne and Morison, 1985). An erosional unconformity separates underlying White Channel silty clay overbank sediment from the iron-stained fluvial gravel unit (Figure 9). The iron-stained gravel unit contains clast-supported and matrix-filled gravel which is distinctly planar-stratified. This gravel unit is interpreted to be nonglacial because of the absence of regionally derived pebble clasts that are immediately evident in the glacially derived Klondike gravels. Preliminary palynologic evaluation of samples taken from the White Channel overbank sediments indicates a Pliocene age due to the presence of Corylus sp. in the floral assemblage (G.S.C. Palyn. No. P2642-9). This indicates that the

overlying iron-stained gravel unit is Pleistocene in age.



Plate 2. Overview of Bonanza Creek
showing the high level White Channel
terraces or benches (view to south).



Plate 3. Typical exposure of White Channel sediment showing complex facies relationships and maximum thickness.



Plate 4. Interbedded Klondike gravel
(darker) and White Channel troughed
facies (lighter) near the mouth of
Bonanza Creek.

- a. MUCK.
- b. STREAM GRAVELS.
- c. TERRACE GRAVELS.
- d. WHITE GRAVELS. } WHITE CHANNEL GRAVELS.
- e. YELLOW GRAVELS. }
- f. KLONDIKE SCHISTS.

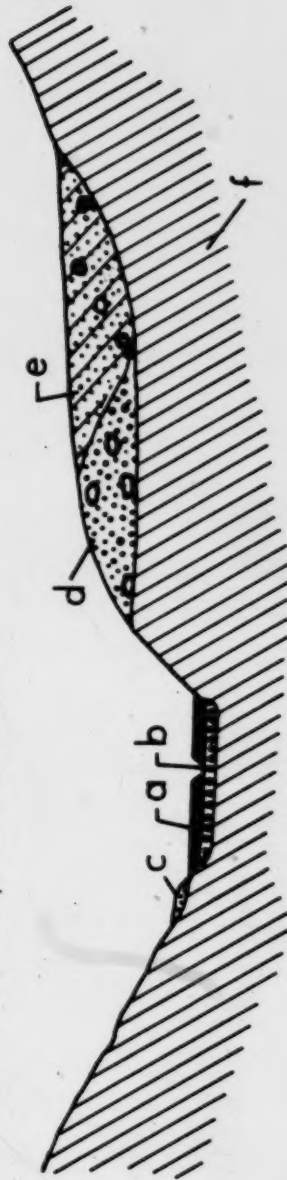


Figure 7: Generalized section across Bonanza valley below Eldorado Forks (from McConnell, 1907).

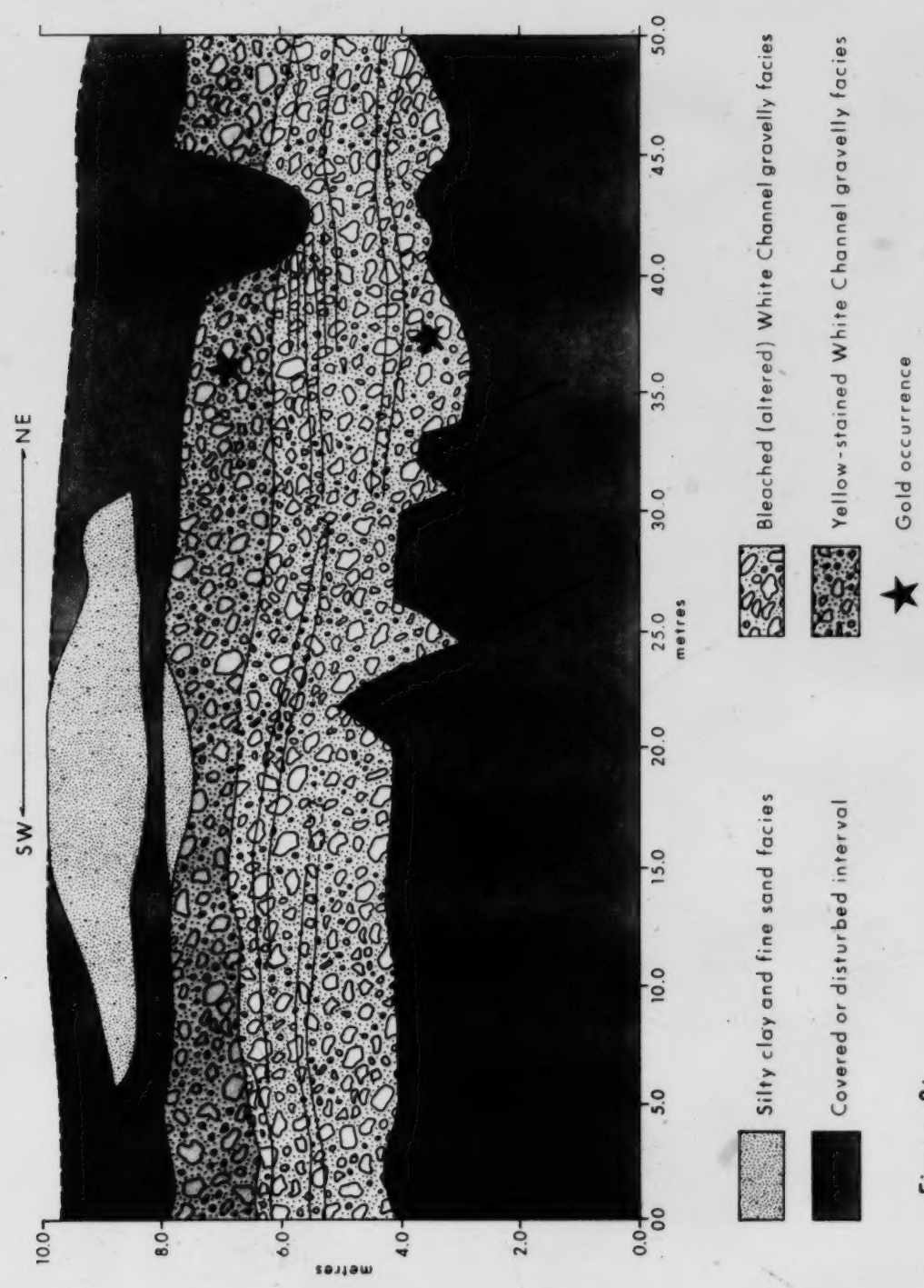


Figure 8:

Sketch of White Channel exposure showing yellow-stained upper component.



Plate 5. Example of White Channel
upper yellow-stained and lower altered
gravel units. See Figure 8 for a sketch
of this exposure.

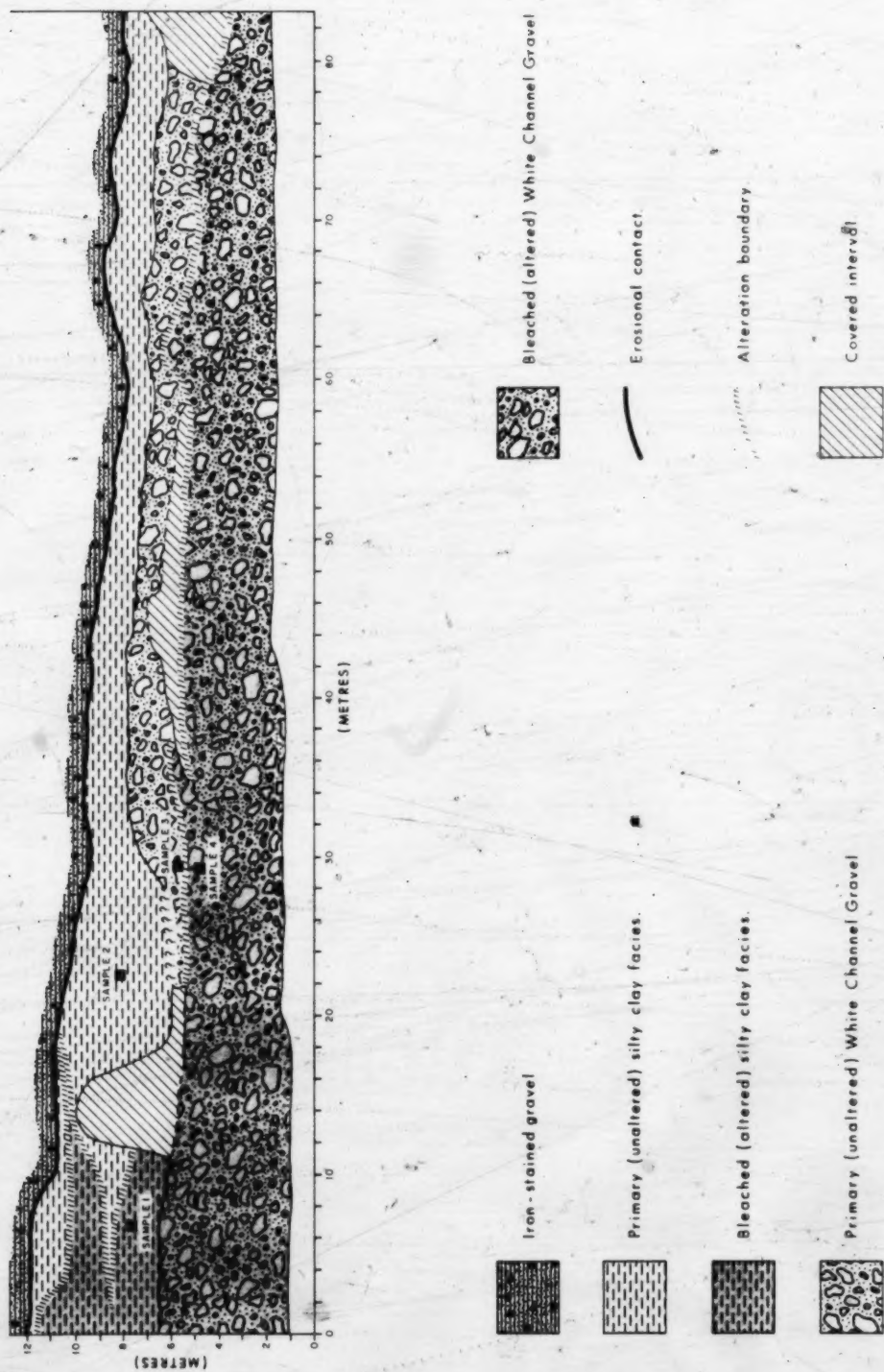


Figure 9: Exposure at Dago Hill showing gravelly sequence overlying White Channel clastic sediment and alteration front (from DuFresne and Morison, 1985).

D. YUKON PLACER DEPOSITS

Unconsolidated placer deposits in the Cordillera are found in five generalized stratigraphic periods (Table 1). Pliocene and Pleistocene nonglacial and/or preglacial placer alluvium is generally found as terraces buried beneath overburden such as glacial drift and nonauriferous alluvium. Interglacial placer alluvium is found as valley bottom fill and low terraces in drainage basins which have escaped glacial scour. During glacial intervals ice marginal and proglacial sedimentation, and alpine morainic deposition (Boyle, 1979) can incorporate detrital gold from regionally derived bedrock or paleoplacer sources. Recent placer deposits are found as alluvial plains and terraces, and colluvium or slope deposits.

Yukon is unique as the terrain ranges from unglaciated west-central and northern regions to recently glaciated southern regions. As a result of this, placer deposits in Yukon were formed during all five stratigraphic intervals described above.

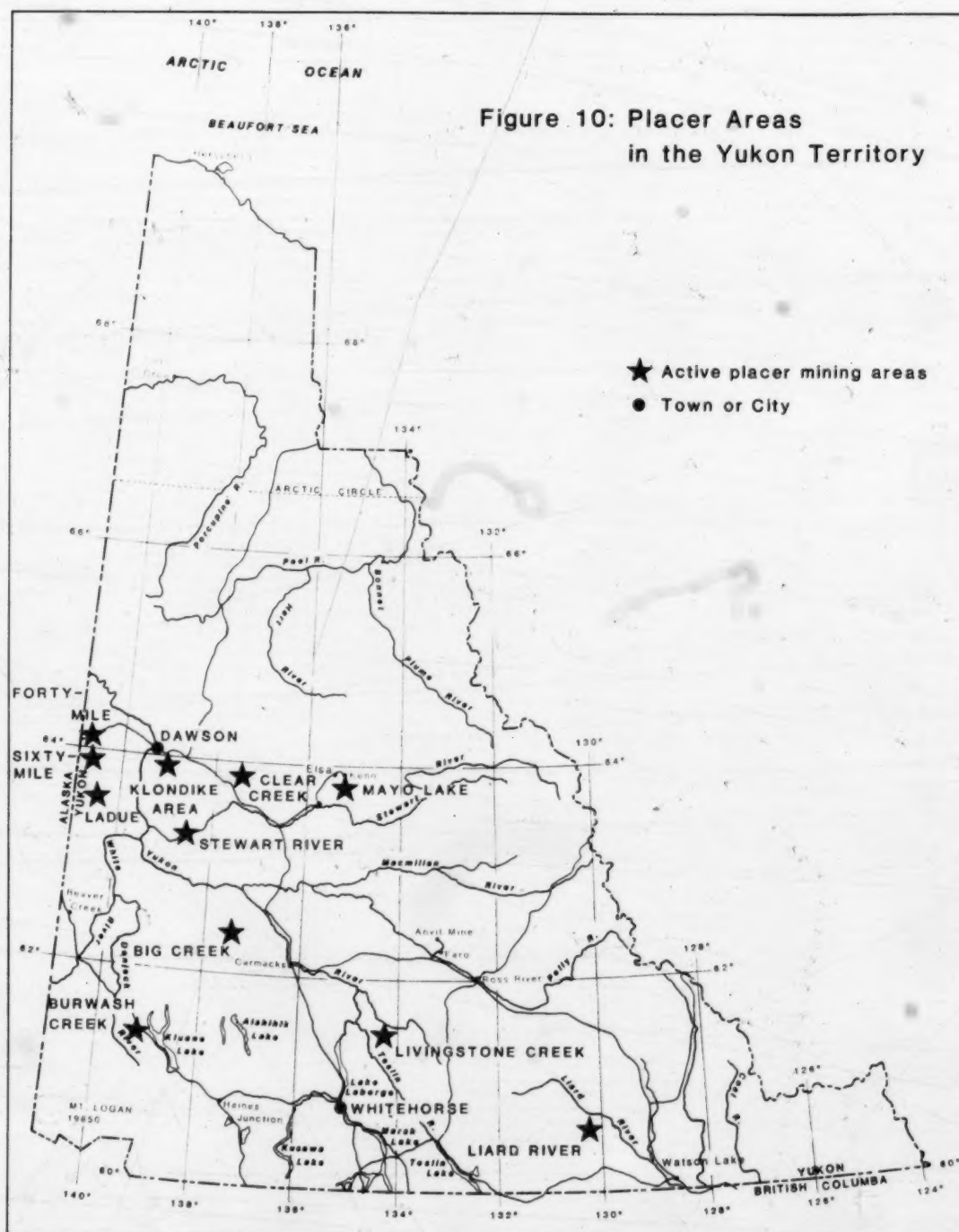
Economic placer mining areas are found throughout central and southern Yukon (Figure 10) and include a variety of placer deposit settings, each with a unique depositional history. For example, in Clear

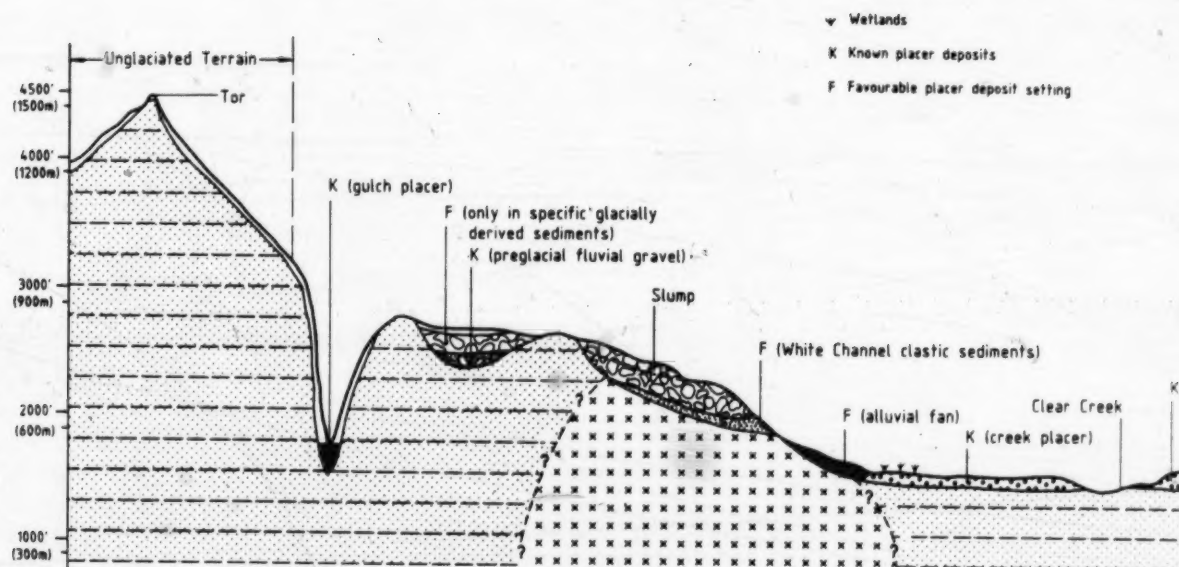
Creek drainage basin (Figure 10), placer gold may be found in valley bottom creek and gulch gravel, glacial gravel, and buried preglacial fluvial gravel (Figure 11). Distribution of placer gold in creek gravel is discontinuous, with discrete concentrations present throughout the entire gravelly sequence. This distribution reflects the braided river environment interpreted for Clear Creek valley bottom gravel deposits (Morison, 1983, 1985). Proglacial and ice marginal gravels representative of the pre-Reid glacial advance (Hughes et al., 1969) may also contain placer gold (Figure 12). Grade of this type of placer is lower than fluvial placers because of the large volume of poorly sorted glacial gravel which has "incorporated" auriferous preglacial sediment with minimal concentration of heavy minerals (Morison, 1985). Buried placer deposits include preglacial fluvial gravel and White Channel clastic sediment (Figure 11). Preglacial fluvial gravel was deposited during a period of high level gravelly stream sedimentation during the Pleistocene before the pre-Reid advance. This type of buried placer deposit is covered by a sequence of pre-Reid glacial drift (Figure 13) which has not eroded the underlying auriferous stream gravel. Depositional processes such

as melt-out and resedimentation formed terraces of pre-Reid glacial drift near the limit of glaciation. These depositional processes are typical of ice marginal areas where basal transport and subglacial erosion are reduced in intensity. Thus areas of glacial drift proximal to the limit of the pre-Reid glacial advance are favourable exploration targets for buried fluvial placer deposits (Morison, 1985). Additional factors such as drainage reversals as a result of Pleistocene glaciation in central and southern Yukon (Tempelman-Kluit, 1980) should also be considered in the search for buried placer deposits.

TABLE 1. STRATIGRAPHY AND GENERAL CHARACTERISTICS OF PLACER GOLD DEPOSITS IN CANADA (FROM MORISON, IN PRESS).

TIME PERIOD	Tertiary Pliocene	Quaternary Pleistocene	Recent
PLACER ENVIRONMENT & GEOMORPHIC LOCATION	Buried alluvial sediments in benches above valley floors	Preglacial or Nonglacial Buried alluvial sediments in benches above valley floors; valley fill alluvial sediments; alluvial terraces	Glacial Benches of pro- glacial and ice contact deposits; terminal valley moraines and alpine drift
GENERAL SEDIMENT CHARACTERISTICS	Mature sediments; well sorted alluvium with a diverse assemblage of sediment types	Locally derived gravel lithology; moderately to well sorted alluvium which is crudely to distinctly stratified	Regionally derived gravel lithology; variable sorting and stratification depending upon type of glacial drift
GOLD DISTRIBUTION	Greater concentra- tion with depth	Discrete concentrations throughout to pay streaks at base of alluvium	Discrete concentrations throughout to pay streaks at base of alluvium; pay streaks follow slope morphology and strandline trend
MINING PROBLEMS	Thick overburden	Thick overburden; variable grade	Variable grade and low volume of auriferous sediment
EXAMPLES	"White Channel Gravel" of the Klondike area, Yukon Territory	Preglacial fluvial gravels, Clear Creek drainage basin and unglaciated terrain	Valley bottom creek and gulch placers in Clear Creek drainage basin, Yukon Territory;



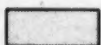


LEGEND FOR SCHEMATIC PROFILE

QUATERNARY Recent



Alluvium (Clear Creek sediments)

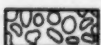


Alluvium (including gulch alluvium with abundant colluvial material from valley sides and alluvial fans and aprons)



Colluvium

Pleistocene

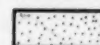


Pre-Reid glacial drift (this represents a pre-Wisconsin Cordilleran ice advance (Hughes et al, 1969) and includes till deposits, resedimented till sequences and glaciofluvial sediments)



Alluvium (preglacial fluvial gravel)

TERTIARY Pliocene (?)



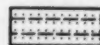
Fine and coarse clastic sediment ("White Channel Gravel")

CRETACEOUS



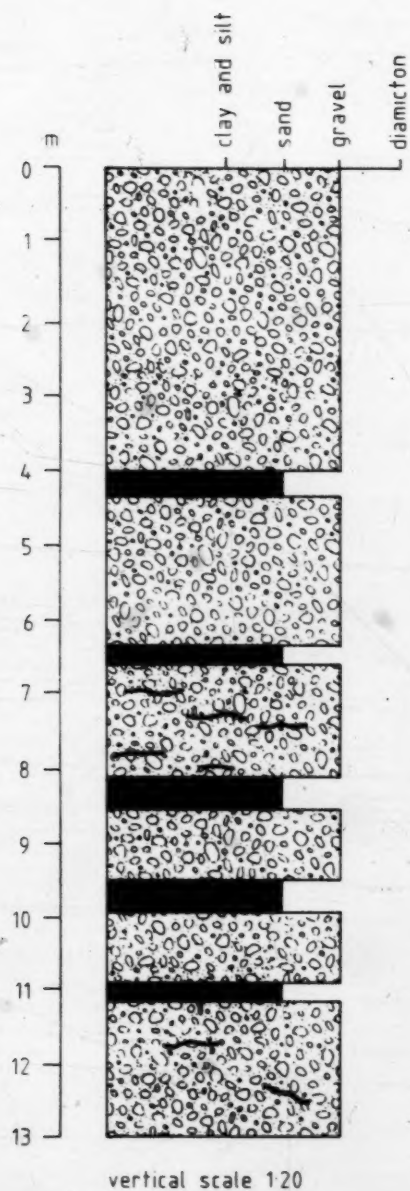
Granite, granodiorite, quartz monzonite (after Bostock, 1964), commonly disintegrated and crumbly

ORDOVICIAN (?) or EARLIER



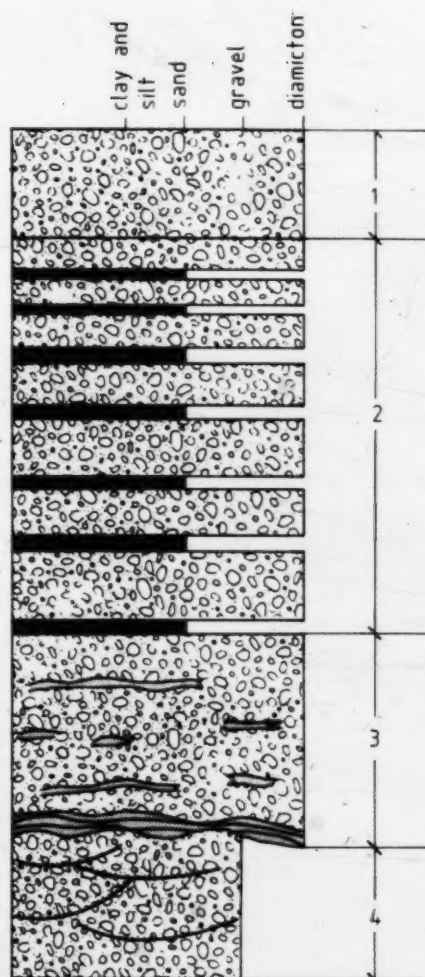
Schists, quartzite, phyllite, limestone (after Bostock, 1964)

Figure 11: Schematic profile of Clear Creek drainage basin showing types of placer deposits and surficial materials (from Morison, 1985).



Sequence of auriferous glacial sediments at the mouth of Left Clear Creek. These clastic sediments are summarized as an interbedded sequence of poorly sorted, massive to crudely stratified gravel, and massive to laminated sand and silt. The gravel is clast supported with a silty sand matrix, and contains subrounded to subangular clasts which are both regionally and locally derived.

Figure 12: Sequence of pre-Reid ice marginal gravel (from Morison, 1985).



Quartz-Chloritic Schist

vertical scale 1:20

Unit 1- Diamicton which has a silt to sand matrix, and contains both local bedrock fragments and glacial erratics. The bottom contact is sharp and follows underlying slope morphology. This unit is interpreted as colluvium.

Unit 2- Stratified sequence of massive diamicton and sorted fine clastic sediments. The diamicton has a matrix texture which ranges from silty sand to fine sand, and contains subangular to subrounded clasts. The fine clastic interbeds range from clay to fine sand, and the lower contact for this unit is gradational. This sequence is interpreted as a series of resedimented melt-out till units.

Unit 3- Diamicton which has a matrix texture of clayey silt, and contains subrounded to rounded clasts. Sedimentary structures include intrabeds and lenses of sorted sand and silt. The bottom contact is characterized by an irregular bed of laminated silt and fine sand. This unit is interpreted as a melt-out till.

Unit 4- Preglacial fluvial gravel which is auriferous. The gravel is clast supported, matrix filled, and trough cross-stratified. Occasional disorganized openwork gravelly beds, and trough cross-stratified sandy beds are also present. These gravels were deposited in a multi-channelled river environment.

Figure 13: Stratigraphy and sedimentology of a buried placer deposit at the mouth of Left Clear Creek (from Morison, 1985).

E. SEDIMENTOLOGY OF FLUVIAL PLACER DEPOSITS

It is appropriate at this point to review aspects of sedimentology in relation to types of fluvial depositional environments which have the ability to concentrate heavy minerals. The application of fluvial processes, facies interpretations and related heavy mineral distribution to placer deposits has been investigated by authors such as Minter and Toens (1970), McGowen and Groat (1971), Minter (1975a, 1975b, 1976), Mosley and Schumm (1977), Minter (1978), Smith and Minter (1980), Pretorius (1981), Nami (1983), Smith (1983), Slingerland (1984), Krapez (1985). The following discussion will outline types of fluvial placer deposits and processes responsible for concentration of heavy minerals.

Concentration of heavy minerals in the fluvial environment can occur on many scales (Table 2). For example, the system scale refers to regional placer settings, the bar scale refers to placer deposition at the geomorphic landform scale (i.e. point bars), and the bed scale involves heavy mineral distribution at the bedform level (Slingerland, 1984; after Smith and Minter, 1980). Modern fluvial systems which have the ability to concentrate heavy minerals can be

broadly classified as creek and gulch, and river and stream placer deposits (Boyle, 1979).

Creek and gulch fluvial systems are associated with deeply dissected terrain which has highly weathered and colluviated slopes. Valleys are narrow, restrictive, incised, and associated with youthful or rejuvenated terrain. Discharge is seasonal and gradients are moderate to high (Boyle, 1979). The resulting alluvial deposit is generally thin, and the gravelly sediments are poorly sorted, distinctly to crudely stratified, angular, and locally derived. Pay zones are regular, laterally consistent and on/or close to the bedrock surface in the thalweg of the gulch streambed (Figure 14). The gold is generally coarse-grained and the accompanying heavy mineral suite is closely associated with local bedrock mineralization (Boyle, 1979).

Stream and river placers are those formed in wide valleys, and include meandering and braided streams and alluvial fan or fan delta systems. In meandering stream environments, heavy minerals may accumulate in main channel bedforms such as dunes or lag deposits. Point bar deposition on the inside curve of meander scrolls during flood conditions is also a favourable site for heavy mineral deposition (Figure 15). The

distribution of detrital gold in a braided river environment is sporadic and discontinuous (Smith and Minter, 1980). This is related to the variable and transitory nature of braided river deposition. Smith and Minter (1980) have summarized braided stream flow patterns as convergent, parallel and divergent (Figure 16). Typical areas which are favourable for heavy mineral concentration include width restrictions ("sluiceways") between stable banks and bank-hugging bars, channel bends, channel junctions and generally where stream flow is convergent (Smith and Minter, 1980; Smith, 1983). These areas are characterized by increased turbulence and higher stream velocities, with selective removal of lighter minerals and a resultant lag deposit of heavy minerals (Smith, 1983). Fluvial processes at the bedform level involve the segregation of grains by size, shape, and density through selective sorting mechanisms such as entrainment, suspension, shear and transport (Slingerland, 1984). Convergent flow enhances entrainment, shear, and transport sorting processes. Channel bedforms such as dunes, and planar bed flow and bar bedforms such as avalanche foresets and ripples concentrate heavy minerals through convergent sorting processes (McGowen and Groat,

1971; Smith and Minter, 1980; Slingerland, 1984). Areas of parallel or divergent flow (Smith and Minter, 1980), are characterized by suspension sorting (Slingerland, 1984) through decreased stream competence and selective deposition. It is thus reasonable for heavy minerals to accumulate in these areas, however concentration and relative enrichment should be substantially lower than in areas of convergent flow if one considers the relative sorting processes. In addition, entrapment of heavy minerals during aggradation of proximal channel gravel as either diffuse gravel sheets (Hein and Walker, 1977), or as unit barforms is possible (Minter and Toens, 1970; Smith and Minter, 1980). Gravelly sediments and incorporated heavy minerals are temporarily stored in bars, and upon erosion due to change in discharge conditions these sediments are mobilized and redeposited (Smith and Minter, 1980). These local point sources of heavy minerals can then either be reworked and redeposited as a higher concentrate or distributed randomly throughout the alluvial sediments depending upon the change in flow regime (Smith and Minter, 1980). Thus, it is apparent for placer mineral concentration to occur, local point sources and ideal hydraulic conditions are required

(Smith and Minter, 1980). Point sources of heavy minerals are transitory, and eventually become buried and preserved in alluvial sediments. Smith and Minter (1980) maintain that predicting sedimentologic conditions necessary for placer development is possible, but predicting local point source locations is very difficult. Thus, two identical sedimentary beds may have totally different heavy mineral suites. Pay zones in stream and river placers range from linear, parallel to channel system paystreaks (Smith, 1983) to discontinuous concentrations throughout the entire gravelly sequence.

Other areas in the fluvial environment which are favourable for concentrating heavy minerals include tributary junctions where turbulent flow or "helicoidal cells" (Mosley and Schumm 1977) promote sediment reworking.

Lithofacies types which have been documented to contain placer gold in the Witwatersrand basin in South Africa include: poorly-sorted matrix-supported conglomerate; clast-supported conglomerate; channel-based (i.e. scoured) conglomerate; conglomerate lags or "diffuse gravel sheets"; horizontally stratified sandstone; and trough cross-stratified sandstone (Krapez, 1985). This

demonstrates the wide range of lithofacies types which may contain placer gold. Krapez (1985) interprets the matrix-supported conglomerates to represent debris flows, and concludes that there is no "sedimentologic control of gold mineralization in debris-flow deposits". Only the stream deposits demonstrate sedimentologic and depositional control with respect to heavy mineral concentrations. It is further concluded that local gold provenance is the major criterion for determining mineralization distribution and grade (Krapez, 1985).

TABLE 2.

OBSERVED SITES OF HEAVY MINERAL PLACERS IN THE FLUVIAL SYSTEM
(from Slingerland, 1984)System Scale (10^4 m)

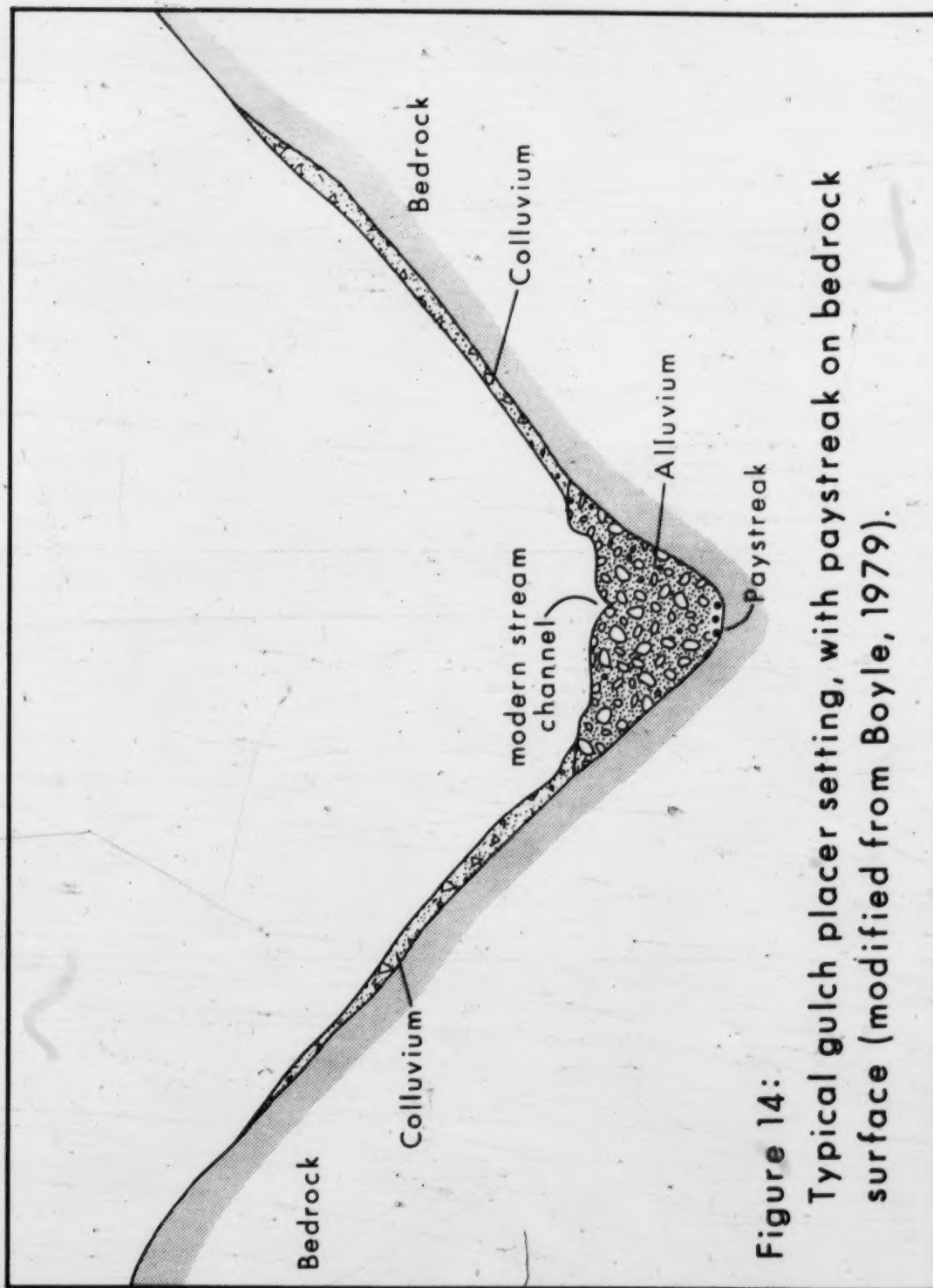
Bands parallel to depositional strike	Smith and Minter (1980); McGowen and Groat (1971).
Heads of wet alluvial fans	Schumm (1977).
Points of abrupt valley widening	Kuzvart and Bohmer (1978); Crampton (1937).
Points of exit of highland rivers onto a plain	Toh (1978).
Regional angular unconformities	Minter (1978).

Bar Scale (10^2 m)

Concave sides of sharp bends	Kuzvart and Bohmer (1978).
Convex banks of meanders	Kuzvart and Bohmer (1978).
Heads of mid-channel bars	Toh (1978); Smith and Minter (1980); Kartashov (1971).
Point bars with suction eddies	Toh (1978); Bateman (1950).
Scour holes, esp. at tributary confluences	Kuzvart and Bohmer (1978); Mosley and Schumm (1977).
Inner bedrock channels and false bedrock	Schumm (1977); Kuzvart and Bohmer (1978); Adams et al (1978).
Bedrock riffles	Cheney and Patton (1967); Toh (1978).

Bed Scale (10^0 m)

Scoured bases of trough cross-strata sets	Toh (1978); McGowen and Groat (1971).
Winnowed tops of gravel bars	Toh (1978); McGowen and Groat (1971).
Tangential toes of foresets	Toh (1978); McGowen and Groat (1971); Smith and Minter (1980).
Thin ripple-form accumulations on dune stoss slopes	Brady and Jobson (1973).
Dune crests	Brady and Jobson (1973).
Dune foreset beds	McGowen and Groat (1971).
Plane parallel laminae	Slingerland (1977).
Leeward side of obstacles	Lindgren (1911).



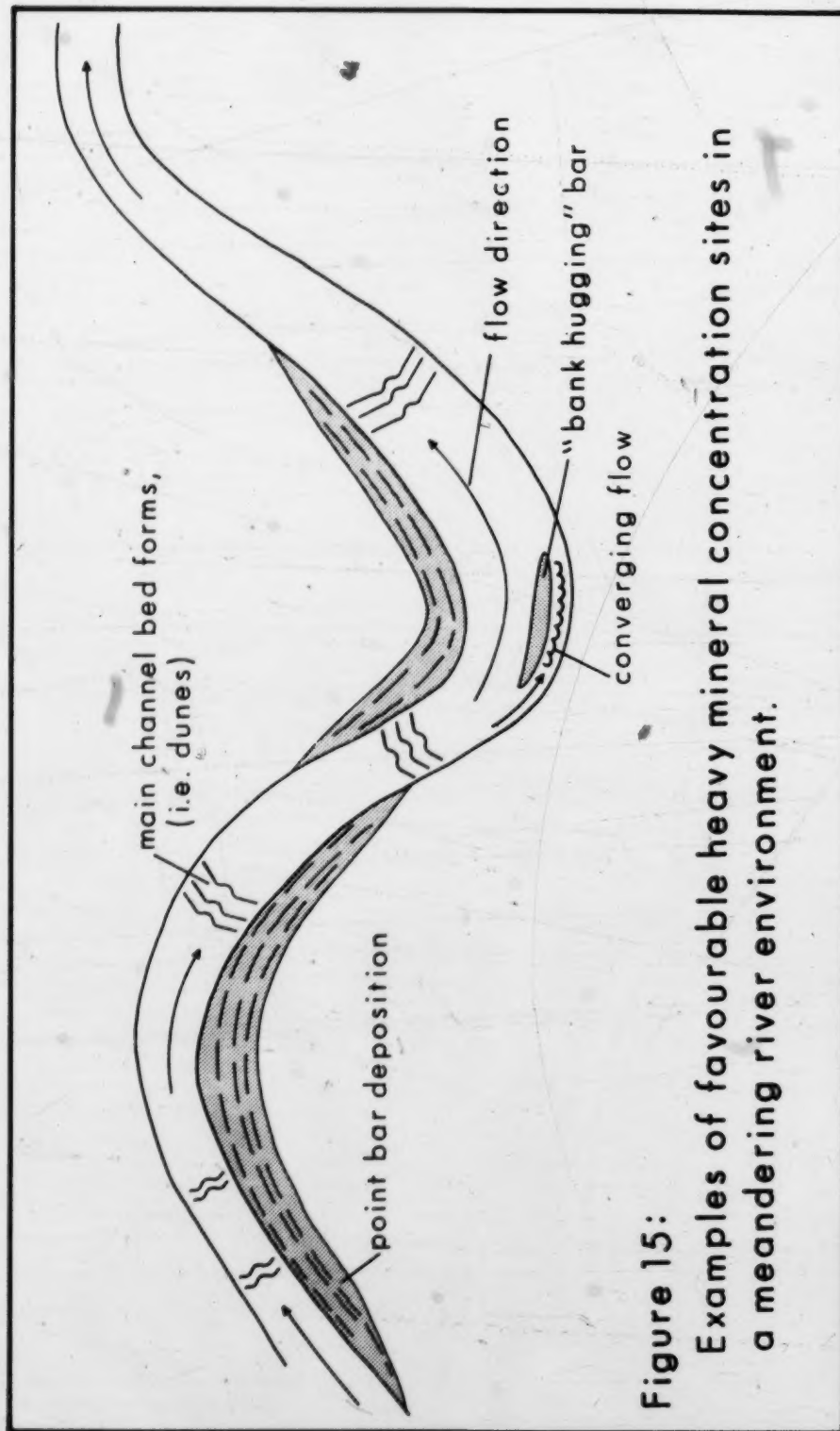
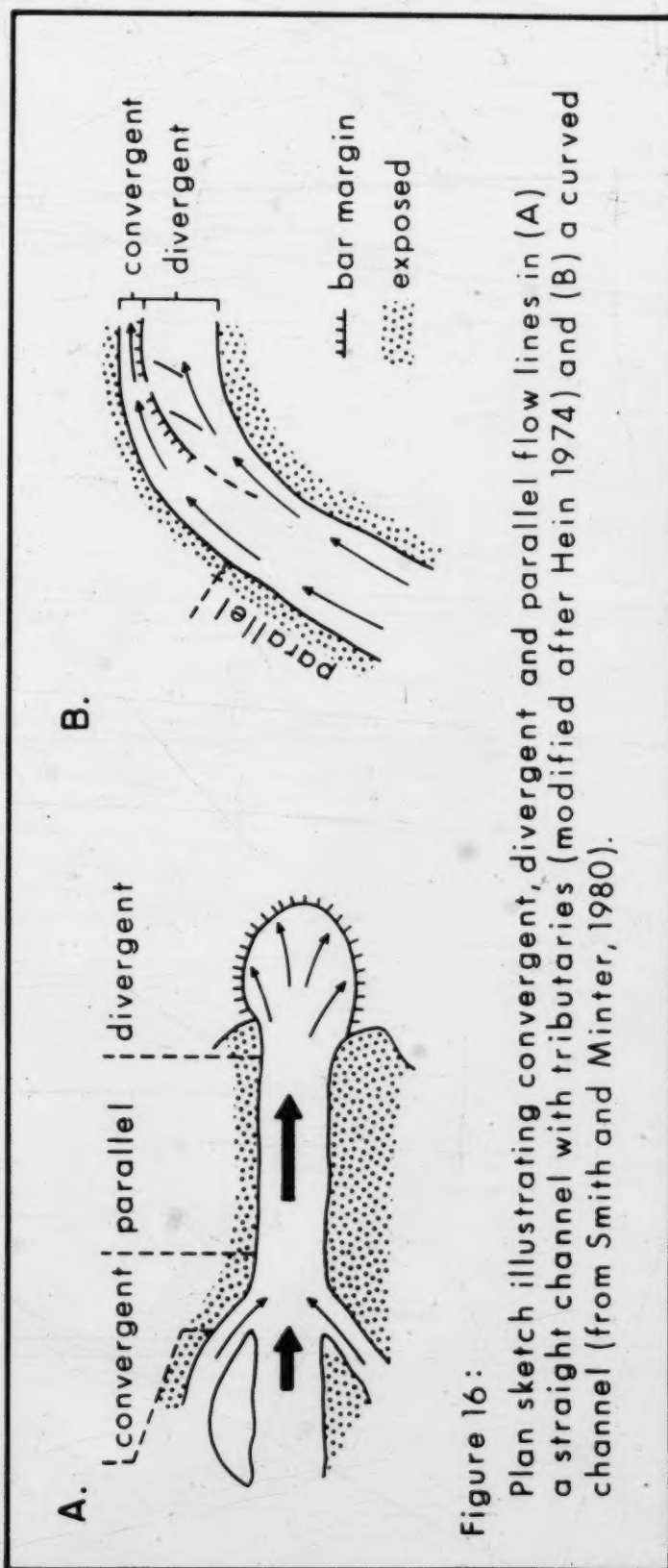


Figure 15:

Examples of favourable heavy mineral concentration sites in a meandering river environment.



Chapter III. FACIES SCHEME AND SECONDARY FEATURES

A. INTRODUCTION

The facies scheme developed for this study is consistent with the concept of Harms et al. (1975, 1982) that facies are homogeneous components which comprise a sedimentary sequence. These homogeneous components may be thought of as "building blocks" (Harms et al., 1982) which are used for the discussion and interpretation of a sedimentary sequence.

The White Channel deposit was measured on a bed-by-bed basis, and the facies scheme was developed and improved during the field season. Facies descriptions include percent abundance, sorting, structure, grading, type of contact (flat, scoured, gradational), bed thickness (range, mean), type of texture (i.e. clast-supported, matrix-filled, openwork), clast angularity, and grain size. Grain size determinations for gravelly beds are based on measurement of the 10-largest clasts (a-axis), and sieve analysis of sediments finer than pebble size. Pebble count data is not included in the facies scheme due to difficulty with the identification of

lithology types in weathered and altered gravel clasts. Gravelly facies comprise 80 % of all beds measured in the White Channel sequence (see Table 3). It is for this reason that gravel has been described and measured in considerable detail.

B. FACIES DESCRIPTIONS

FACIES 1 MASSIVE PEBBLY SAND

This facies is not a common type, and makes up only 1.7% of all beds measured. Beds are laterally discontinuous, and have flat bases. Bed thickness ranges from 0.1 to 0.5 m. thick, and the average thickness is 0.3 m. Average clast size is 5.3 cm, and the maximum observed clast size is 11.6 cm.

Examples: This lithofacies type is found in section intervals 83023, 83025, 83030, and columns 83015, 84011 and 84013.

FACIES 2: MASSIVE, MATRIX-FILLED AND CLAST-SUPPORTED GRAVEL

This facies accounts for 2.6% of all beds measured. It is very poorly sorted, and contains a matrix which ranges from silt to sand. There is no apparent stratification, and crude normal grading can be present. Beds are laterally continuous and bases are flat to slightly scoured. This facies is commonly found as bedded sequences where contacts between beds

are gradational. Also, discontinuous clayey and silty interbeds which contain sand and granule to pebble gravel clasts are found at the base of some beds. Bed thickness ranges from 0.2 to 2.0 m, with an average thickness of 0.8 m. Average clast size is 14.3 cm, and the maximum clast size is 65.0 cm.

Examples: This lithofacies type is found only in column 84013, and is illustrated in Plate 6.

FACIES 3: CRUDELY STRATIFIED, MATRIX-FILLED AND CLAST-SUPPORTED GRAVEL

Relative abundance of this facies increases in a down-section direction, and comprises 22.5% of the total number of beds measured. This gravelly facies is poorly sorted, and contains a matrix texture which ranges from silt to sand. Stratification is planar, discontinuous and is discernable through change in gravelly texture. Typical stratification includes thinner granule to pebble gravel beds which are less commonly openwork, and thicker pebble to cobble gravel beds. Discontinuous sandy lenticular bedding is also characteristic of this facies. Beds are laterally continuous and bases are flat to slightly

scoured. Bed thickness ranges from 0.2 to 2.0 m, with an average of 1.0 m. Average clast size is 21.6 cm, with a maximum observed clast size of 41.5 cm.

Examples: This facies is common in section intervals 83001 to 83008b, 83030 to 83033, 83035 to 83044, and columns 83009, 83034 and 84011. Plate 7 illustrates the facies described above.

FACIES 4: CHAOTIC, MATRIX-FILLED AND CLAST-SUPPORTED GRAVEL WITH SCoured BASES

Facies 4 accounts for 16.8% of total section measured, and occurs throughout the entire thickness of the White Channel deposit. The most important characteristics of this facies includes a disorganized appearance, cluster bedforms, a high matrix content of silt and sand, abundant rounded quartz clasts and scoured bases. Bed thickness ranges from 0.1 to 1.2 m, with an average of 0.6 m. Average clast size is 14.2 cm, with a maximum observed clast size of 70.0 cm.

Examples: This facies is distributed through section intervals 83001 to 83003, 83020 to 83033, 83035 to

83044, and columns 83034 and 84011. Plates 8 and 9 illustrate the physical characteristics of this facies type.

FACIES 5: MASSIVE OPENWORK GRAVEL

This facies is rare, and accounts for only 0.7% of all beds measured. Beds are laterally discontinuous, average approximately 0.5 m thick and bases are flat to slightly scoured. Average clast size is 9.5 cm, with a maximum observed clast size of 11.9 cm.

Examples: This facies is found in section intervals 83024 to 83026, and is illustrated in Plate 10.

FACIES 6: MASSIVE TO LAMINATED MUD AND FINE SAND WITH CONVOLUTIONS AND ORGANIC DETRITUS

This facies occurs as laterally discontinuous lenticular beds which have flat to convoluted bases, and comprises 11.0 % of all beds measured. It ranges from massive clay with fine sand laminae to faintly laminated fine sand and silt with occasional gravel clasts. Bed thickness ranges from 0.02 to 0.8 m, and

averages 0.5m.

Examples: This facies is commonly found in section intervals 83021 to 83029, 83010 to 83011, and column 84011. Plate 11 illustrates this facies type.

FACIES 7: STRATIFIED PEBBLY SAND

This facies accounts for 3.2 % of all beds measured, and is generally associated with gravelly sequences such as Facies 8. Stratification is planar, horizontal, continuous, and visible through bedding of massive sand and massive pebbly sand. Beds are laterally discontinuous and bases are flat. Bed thickness ranges from 0.15 to 0.6 cm, with an average of 0.4 cm.

Examples: This facies is found in section intervals 83002, 83006, 83023 to 83024, and columns 83009, 83015, 83034 and 84013. Plate 12 illustrates this facies type.

FACIES 8: DISTINCTLY STRATIFIED, MATRIX-FILLED AND
CLAST-SUPPORTED GRAVEL

Facies 8 is the most abundant facies type, and accounts for 22.4 % of all beds measured. Relative abundance of this facies type increases in an up-section direction, and is characterized by distinct, continuous horizontal stratification. Stratification is evident by change in gravelly grain size, with typical sequences which include interbedded pebble and cobble gravel beds, and granule to pebble gravel beds. Openwork pockets occur in the finer pebble gravel beds, and the matrix sediment ranges from silt to fine sand. Beds are laterally continuous, and bases are flat to slightly scoured. Bed thickness ranges from 0.1 to 2.0 m, with an average thickness of 0.8 m. The average clast size is 10.0 cm and the observed maximum clast size is 32.1 cm.

Examples: This facies is dominant in section intervals 83003 to 83013, 83020 to 83029 and columns 83009, 83014, 83015 and 84011. Plate 13 illustrates the facies characteristics described above.

FACIES 9: DISTINCTLY STRATIFIED OPENWORK GRAVEL

This facies is very similar in physical characteristics to Facies 8, and comprises 2.2 % of all beds measured. This openwork facies is continuously planar horizontal-stratified, and contains some pockets of matrix-filled pebbly gravel and pebbly sand. Beds are laterally continuous and bases are flat to slightly scoured. Beds range from 0.2 to 0.7 m thick, with an average thickness of 0.4 m. The average clast size is 8.4 cm, with an observed maximum clast size of 17.3 cm.

Examples: This facies occurs in section intervals 83021 to 83023, 83025 and columns 83014 and 84011. Plate 14 illustrates this facies type.

FACIES 10: TROUGH CROSS-STRATIFIED PEBBLY SAND

This facies accounts for 4.1 % of all measured beds, and is spatially associated with facies 11. It is characterized by laterally discontinuous beds of trough cross-stratified pebbly sand, with scoured bases. Rippled laminated silt with organic detritus may also be found in this facies. Bed thickness

ranges from 0.2 to 1.0 m, with an average of 0.3m. The average clast size is 2.8 cm. with a maximum observed clast size of 3.9 cm.

Examples: This facies is found in section intervals 83003, 83010, 83013, 83020, 83025, 83031 to 83032, 83035, 83039, 83043 and columns 83014, 83034 and 84011. Plate 15 illustrates this facies type.

FACIES 11: TROUGH CROSS-STRATIFIED GRANULE TO PEBBLE GRAVEL

Facies 11 accounts for 6.6 % of all measured beds, and is found throughout the entire White Channel deposit. This facies is characterized by clast-supported, and matrix-filled granule to pebble gravel which is distinctly cross-stratified. Beds are laterally discontinuous and bases are scoured. Bed thickness ranges from 0.2 to 2.0 m, with an average thickness of 0.7 m. Average clast size is 6.9 cm, with a maximum observed clast size of 12.2 cm.

Examples: This facies is found in section intervals 83003 to 83006, 83010 to 83013, 83020 to 83030, 83035, 83039, 83042 and columns 83009, 83014, 83015,

and 83034. Plate 16 illustrates the physical characteristics for this facies type.

FACIES 12: SCOOP-SHAPED CROSS-STRATIFIED,
MATRIX-FILLED AND CLAST-SUPPORTED GRAVEL

Facies 12 makes up 4.2 % of all beds measured, and is similar in gravelly characteristics to Facies 8. The main distinction is the trough cross-stratification which is evident through grain size changes from granule and pebble gravel to pebble and cobble gravel. Less common openwork beds and discontinuous sandy beds in association with gravelly troughs are also components of this facies type. Beds are laterally continuous, and bases are flat to slightly scoured. Bed thickness ranges from .35 to 2.0 m, and the average bed thickness is 0.9 m. Average clast size is 9.5 cm, with a maximum clast size of 27.5 cm.

Examples: This facies is found in section intervals 83001, 83004 to 83005, 83020, 83026, 83029 to 83032, 83035, 83038 to 83039, and columns 83015 and 83034. Plate 17 illustrates this facies type.

FACIES 13: SCOOP-SHAPED, CROSS-STRATIFIED OPENWORK
GRAVEL

This facies type is very similar to Facies 9, and accounts for 0.5 % of all beds measured. Stratification is in the form of troughs, and is evident through bedding grain size changes such as fine pebble gravel to pebble-cobble gravel. Beds are laterally continuous and bases are flat to scoured. Bed thickness ranges from 0.8 to 2.4 m, with an average thickness of 1.4 m. Average clast size is 10.3 cm, and the largest clast measured is 18.1 cm.

Examples: This facies is found in section intervals 83024 to 83026.

FACIES 14: PLANAR CROSS-STRATIFIED, MATRIX-FILLED AND
CLAST-SUPPORTED GRAVEL

This facies is very similar to Facies 8 in terms of gravelly characteristics, and accounts for 1.7 % of all beds measured. Stratification is planar, inclined, and often lacking bounding erosional surfaces due to covered intervals on the section face. Beds are laterally continuous, and bases are

flat. Bed thickness ranges from 0.3 to 1.2 m, and has an average of 0.8 m. Average clast size* is 6.0 cm, with a maximum observed clast size of 10.0 cm.

Examples: This facies occurs in section intervals 83003, 83010, 83012, 83029 to 83030, 83033, and columns 83034, 84011 and 84013. Plate 18 illustrates this facies type

TABLE 3. SUMMARY OF WHITE CHANNEL FACIES

Facies	Percent Abundance	Lithology	Gravel Texture	Clast Size (cm)		Bed thickness (m)		Bases
				Average	Maximum	Average	Range	
1	1.7	Pebbly sand	-	5.3	11.6	0.3	0.1-0.5	Flat
2	2.6	Coarse gravel	Clast-supported, matrix-filled	15.2	65.0	0.9	0.2-2.0	Flat, slightly scoured
3	22.2	Coarse gravel	Clast-supported, matrix-filled	17.8	41.5	0.7	0.2-2.0	Flat, slightly scoured
4	16.8	Coarse gravel	Clast-supported, matrix-filled (high content)	14.2	70.0	0.6	0.1-1.2	Scoured
5	0.7	Gravel	Clast-supported, openwork	9.5	11.9	0.5 (approx.)	-	Flat slightly scoured
6	11.0	Mud, fine sand	-	-	-	0.5	0.02-0.8	Flat, convoluted
7	3.2	Pebbly sand	-	-	-	0.4	0.15-0.6	Flat
8	22.4	Gravel	Clast-supported, matrix-filled	10.0	32.1	0.8	0.1-2.0	Flat, slightly scoured
9	2.2	Gravel	Clast-supported, openwork	8.4	17.3	0.4	0.2-0.7	Flat, slightly scoured
10	4.1	Pebbly sand	-	2.8	3.9	0.3	0.2-1.0	Scoured
11	6.6	Fine gravel	Clast-supported, matrix-filled	6.9	12.2	0.7	0.2-2.0	Scoured
12	4.2	Gravel	Clast-supported, matrix-filled	9.5	27.5	0.9	0.35-2.0	Flat, slightly scoured
13	0.5	Gravel	Clast-supported, openwork	10.3	18.1	1.4	0.8-2.4	Flat, scoured
14	1.7	Gravel	Clast-supported, matrix-filled	6.0	18.0	0.8	0.3-1.2	Flat

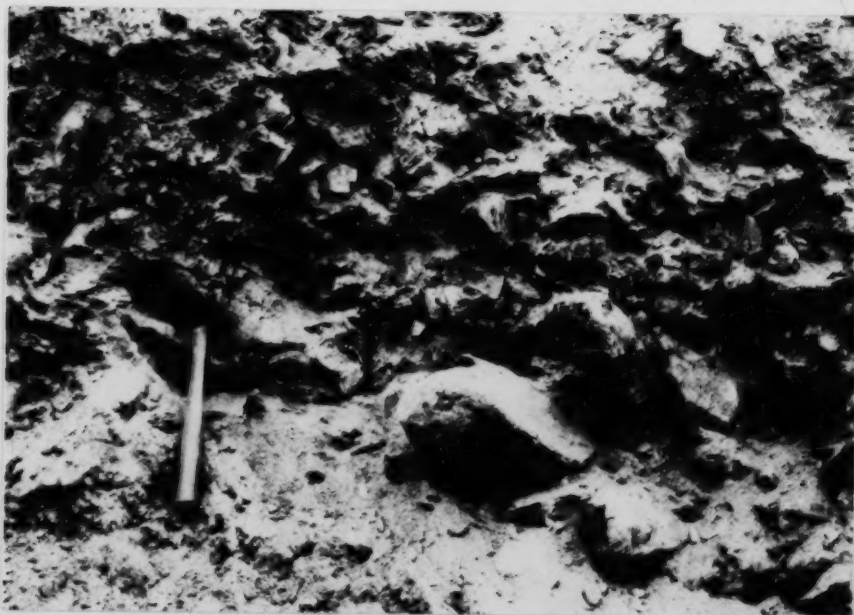


Plate 6. Facies 2: Massive, matrix-filled and clast-supported gravel. Note the very poor sorting and crude normal grading.



Plate 7. Facies 3: Crudely stratified,
matrix-filled and clast-supported gravel.
Note the discontinuous beds of finer
granule to pebble gravel.

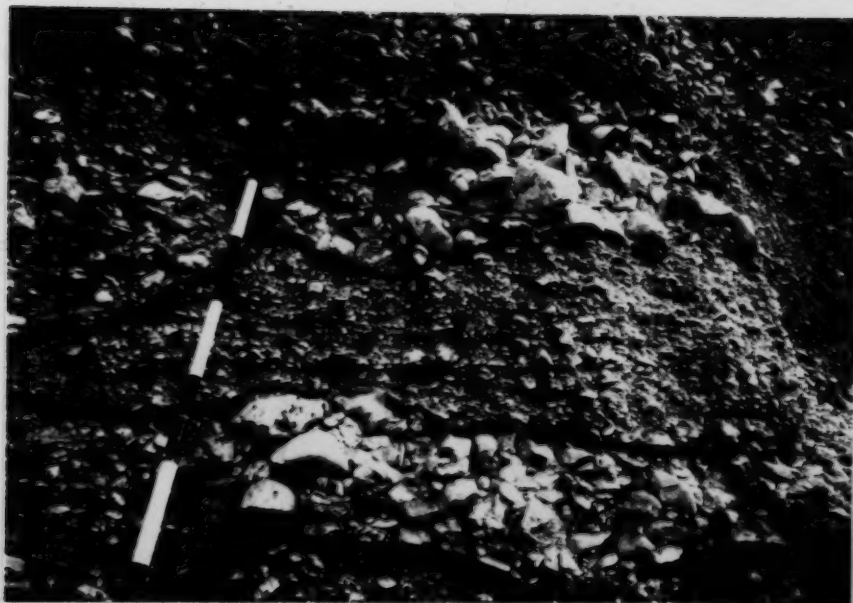


Plate 8. Two examples of Facies 4: Chaotic, matrix-filled and clast-supported gravel, with cluster bedforms and scoured bases.



Plate 9. Cluster bedform of cobble-sized
quartz clasts in Facies 4.



Plate 10. Facies 5: Massive openwork gravel



Plate 11. Facies 6: Massive to laminated
mud and fine sand with convolutions
and organic detritus

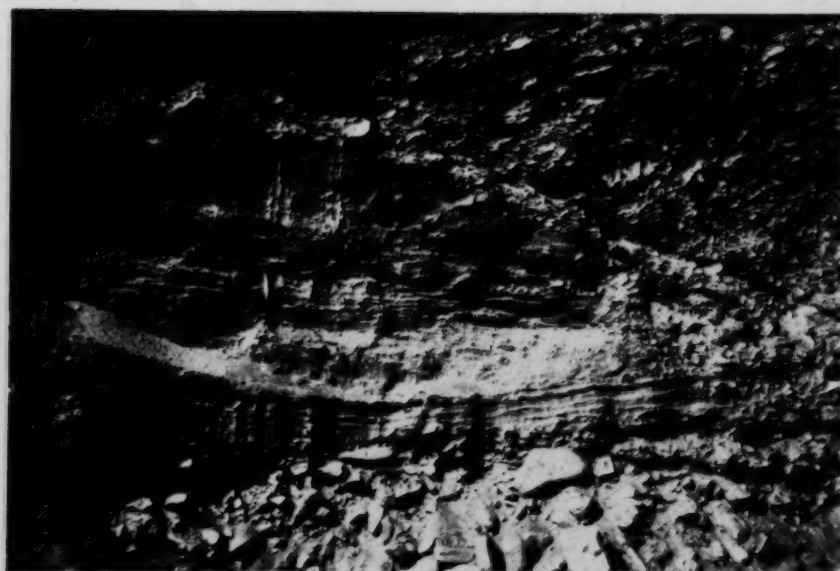


Plate 12. Facies 7: Stratified pebbly sand

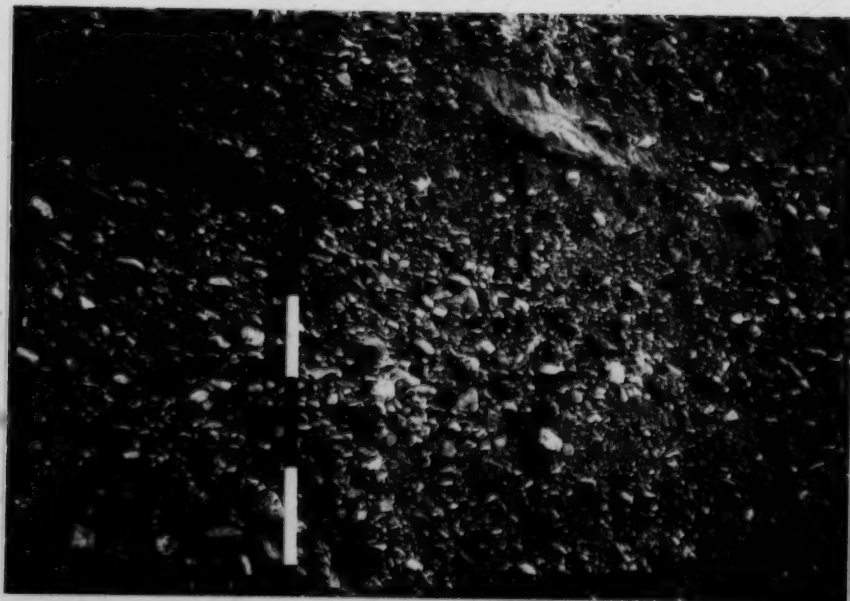


Plate 13. Facies 8: Distinctly stratified,
matrix-filled and clast-supported gravel.
Note the improved sorting and stratification.



Plate 14. Facies 9: Distinctly stratified
openwork gravel.



Plate 15. Facies 10: Trough cross-stratified
pebbly sand



Plate 16. Facies 11: Trough cross-stratified
granule to pebble gravel.

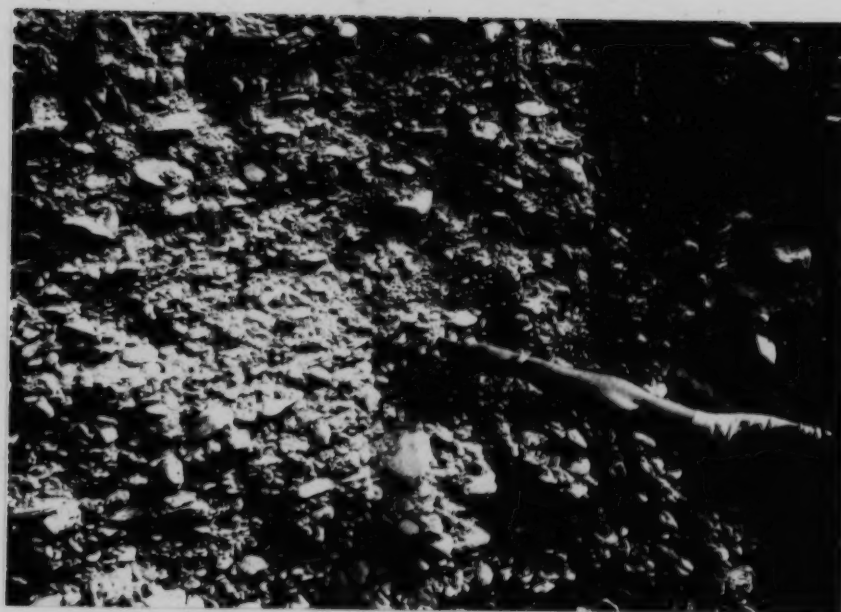


Plate 17. Facies 12: Scoop-shaped cross-stratified, matrix-filled and clast-supported gravel.



Plate 18. Facies 14: Planar cross-stratified,
matrix-filled and clast-supported gravel.

C. CRYOGENIC FEATURES

Cryogenic features such as ice wedge casts in gravelly facies (Plate 19) and fossil frost cracks in sandy facies are generally found between the 22 to 26 m levels in the White Channel sequence (see Appendix C). This indicates climatic cooling during aggradation, and records the first evidence of permafrost development in the White Channel sequence. The vertical position of these frost features is important as they indicate either climatic cooling during the Pliocene, or record the first evidence of Pleistocene sedimentation. Further work is required on the types and stratigraphic significance of cryogenic features in White Channel sediments.

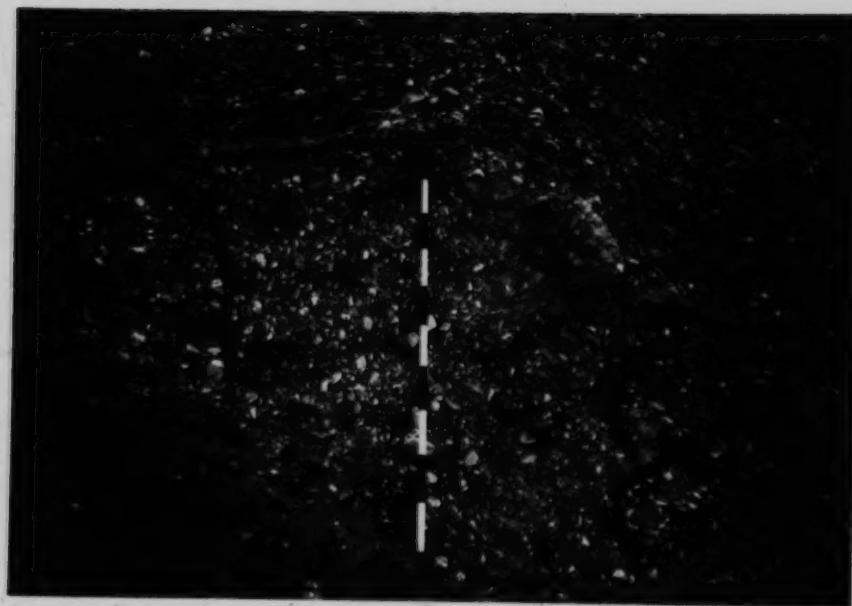


Plate 19. Ice wedge cast.

D. WHITE CHANNEL ALTERATION

White Channel alteration occurs as a clay alteration in fine and coarse sediments, and underlying bedrock (Plate 20). Lithofacies characteristics are either destroyed or masked through replacement of primary sediment by secondary clays (Dufresne and Morison, 1985). Clasts in altered gravel are soft, decomposed (Plate 21) and crumble easily upon thawing (Tempelman-Kluit, 1982). Tempelman-Kluit (1982) was the first to suggest that alteration processes may relate to the apparent gold enrichment in the lower portion of the White Channel sequence. An exposure at Dago Hill (Figure 3) illustrates the irregular relationship between altered and primary White Channel silty clay facies (Figure 9). These stringer-like beds (Plate 22) are clearly not sedimentary in origin, and outline the geochemical front or limit of fluid migration in White Channel sediment (Dufresne and Morison, 1985). The altered zone in White Channel sediment has a maximum thickness of 40 m, and is traceable in both Hunker Creek and Bonanza Creek drainage basins. Dufresne et al. (1985) suggest that alteration is the result of epithermal processes which are also

responsible for gold sources in the Klondike.



Plate 20. Examples of clay alteration in White Channel gravel. The lighter bleached sediments have been replaced by secondary clays, and the limit of fluid migration is outlined near the tops of the exposures.





Plate 21. Soft, decomposed clast in
White Channel gravel (beside knife).

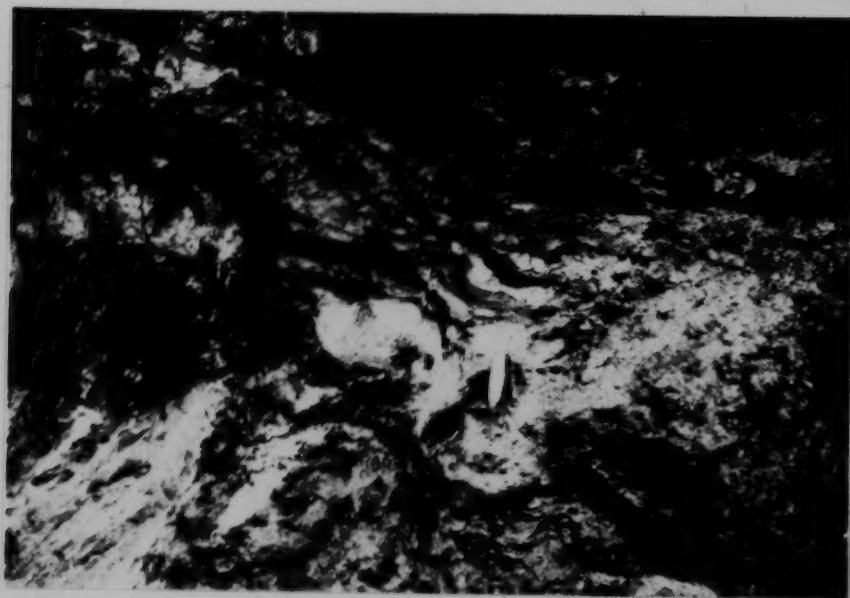


Plate 22. "Stringer-like" relationship
between altered and unaltered White Channel
silty clay facies (at knife).

Chapter IV. PROCESSES OF DEPOSITION

A. SORTING AND GRAIN SIZE CHARACTERISTICS

Sorting characteristics of the gravelly facies in the White Channel deposit was determined both visually during field descriptions and through grain size sieve analysis (see Field Techniques and Laboratory Methods). Results from sieve analysis were plotted on ternary diagrams as percentages of gravel, sand and mud. The system developed by Folk (1954) was used for classification of gravelly sediment types in the White Channel sequence (Figure 17). It is important to note that quantitative evaluation of sorting characteristics for the gravelly facies in the White Channel deposit is difficult due to the abundance of weathered, crumbly schist clasts which skew the results for sand and mud size fractions. Accordingly, grain size analysis must be viewed as a qualitative estimate only.

All of the gravelly facies in the White Channel sequence have a polymodal size distribution (Harms et al., 1982, p.6-2). The ternary diagram for crudely stratified and chaotic gravelly facies show they plot within the muddy sandy gravel field (Figure, 18).

Facies 4 (chaotic gravel) contains the highest percentage of mud of all gravelly facies sampled. Clasts in facies 4 are dominantly competent quartz, and as a result the mud content shown in the ternary plot is reasonable. The stratified facies plot as chiefly muddy sandy gravel also (Figure 19). However, there is a distinct trend for the points to align and for some to fall within the sandy gravel field. This indicates a matrix with a reduced mud content and an improvement in sorting characteristics. The cross-stratified facies plot as muddy sandy gravel, sandy gravel, gravelly sand and muddy sand (Figure 20). This demonstrates the wide range of gravelly sediment types which are cross-bedded. In summary, the overall tendency of gravelly facies to plot in the muddy sandy gravel field demonstrates the polymodal and poorly sorted nature of the White Channel deposit.

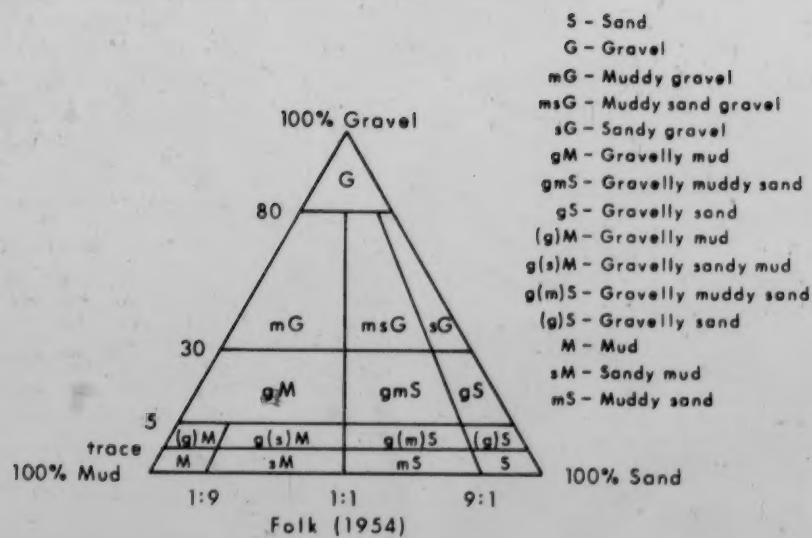


Figure 17: Ternary plot for classification of sediments according to Folk (1954).

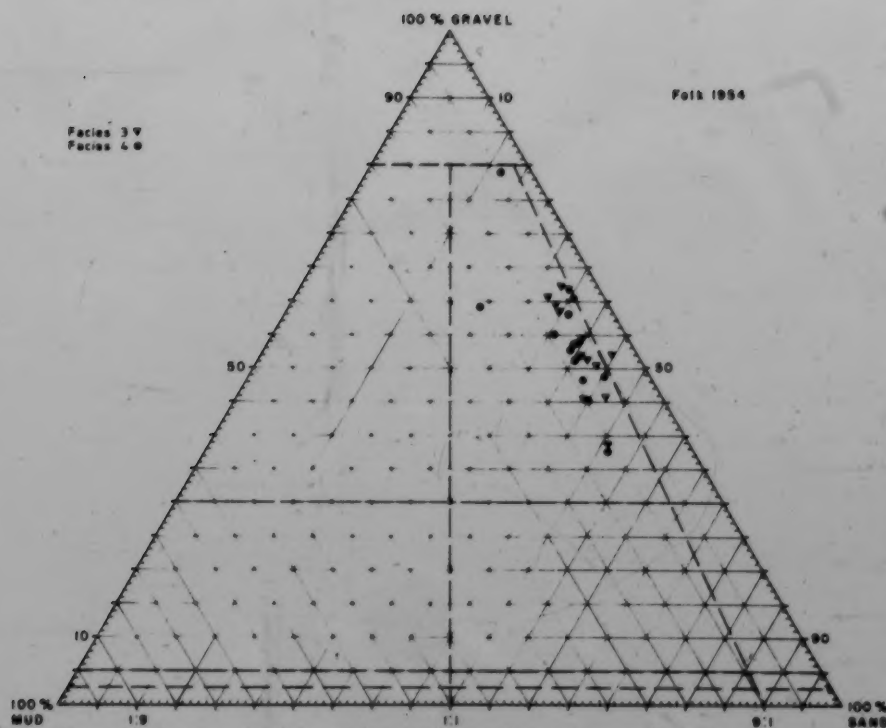


Figure 18: Ternary plot for crudely stratified and chaotic gravelly facies.

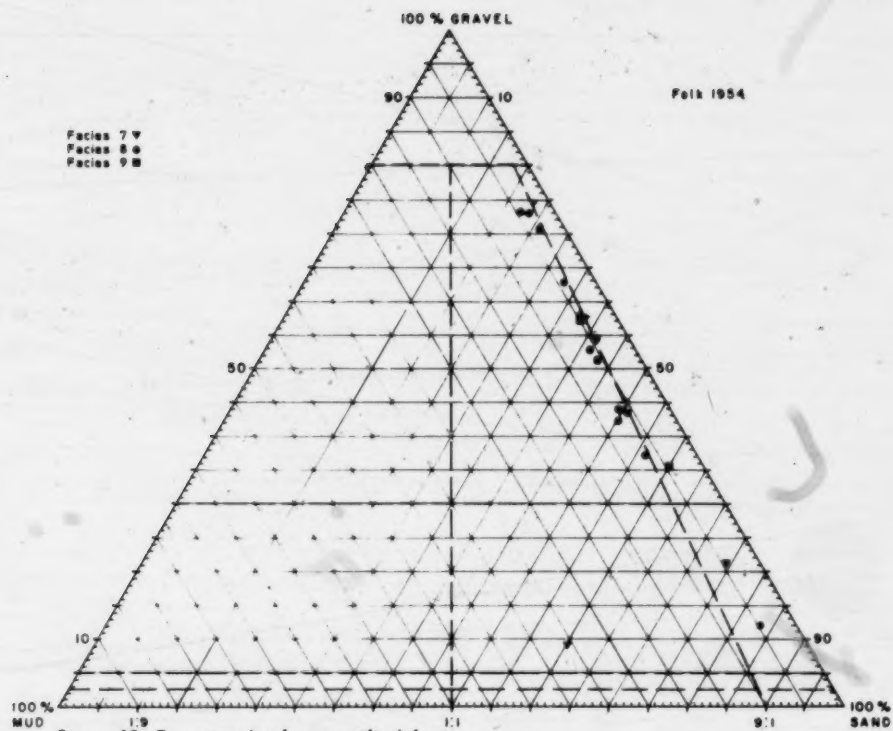


Figure 19: Ternary plot for stratified facies.

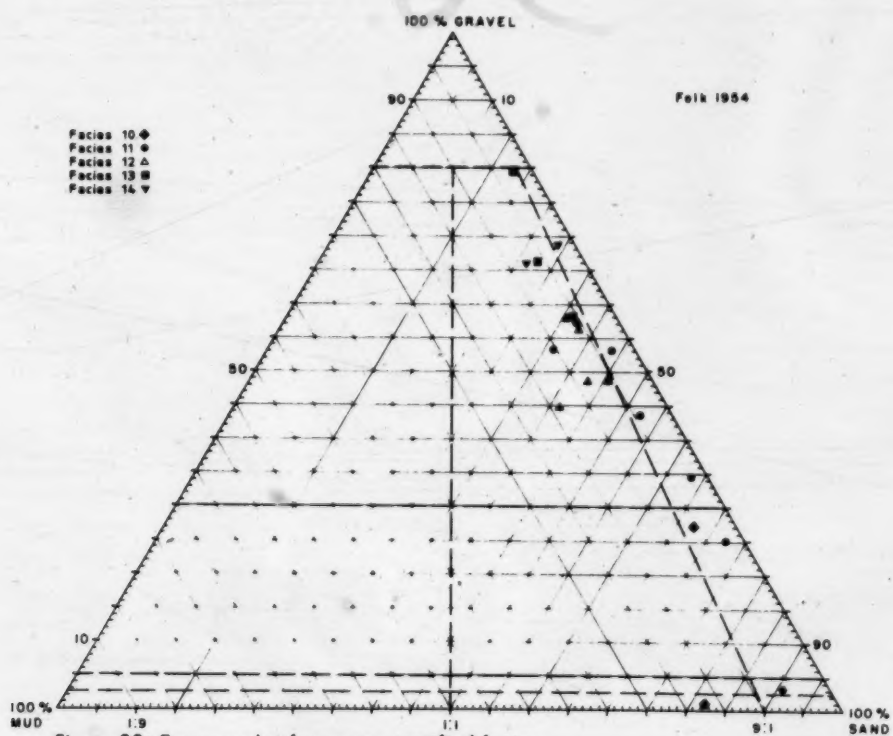


Figure 20: Ternary plot for cross-stratified facies.

B. GRAVEL FABRIC

Fabric measurements were taken to aid in the genetic interpretation of gravelly facies and in particular for gravel beds with crude sedimentary characteristics. Fabric was measured on 100 elongate pebbles with a long-axis (a-axis) to intermediate axis (b-axis) ratio of at least 2:1. Measurements included the strike and dip of the a-b plane, and type of apparent imbrication. Strike frequencies were plotted in 10^0 class intervals as rose diagrams. Strike frequency patterns were visually evaluated for type of modal distribution according to the number of dominant class intervals. Vector means were calculated for bimodal distributions (see Appendix B) according to the method outlined by Curray (1956) for vector analysis of sedimentary particles.

The rose diagram for facies 8 (distinctly stratified gravel) shows a polymodal distribution (Figure 21). Imbrication type for this facies is a well organized (98 %) a-axis transverse to flow, and b-axis imbricate upstream [a(t) b(i); Harms et al., 1982] type. Scattered strike frequency distributions may be associated with bar form sedimentation where stream currents moving across bar tops and fronts

rework previously deposited gravel clasts (Hein, 1984). Both channel and bar deposits may have b-axis imbrication when the majority of gravelly sediment is being transported as bedload.

Facies 3 (crudely stratified gravel), has a wide range of strike frequency distributions which range from bimodal to polymodal and multimodal patterns (Figures 22 a to e). Imbrication types from 300 observations range from 60 to 70 % a-axis upstream and 30 to 40 % b-axis upstream types. This type of imbrication pattern is found in channels where the coarser gravel clasts have a b-axis imbricate fabric, and finer gravel clasts have an a-axis imbricate fabric type (Hein, 1984). Hein (1984) attributes the current parallel long axis orientation of clasts due to reworking of bed material by pivoting around previously deposited sediments or through intermittent saltation.

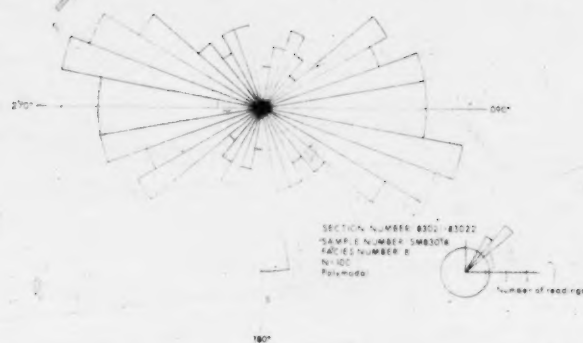


Figure 21: Rose diagram for strike orientation of a-b planes measured for elongated pebbles from facies 8.

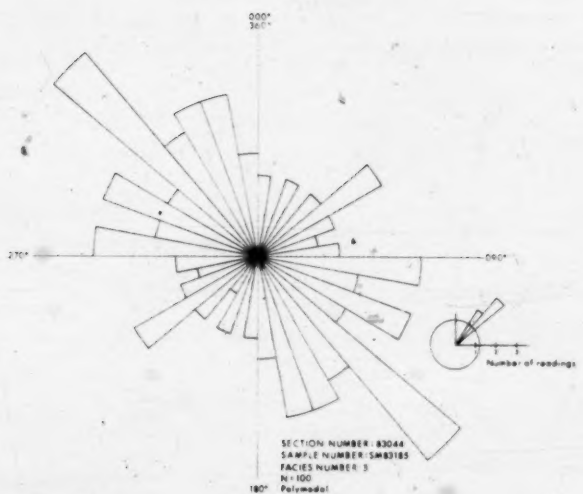
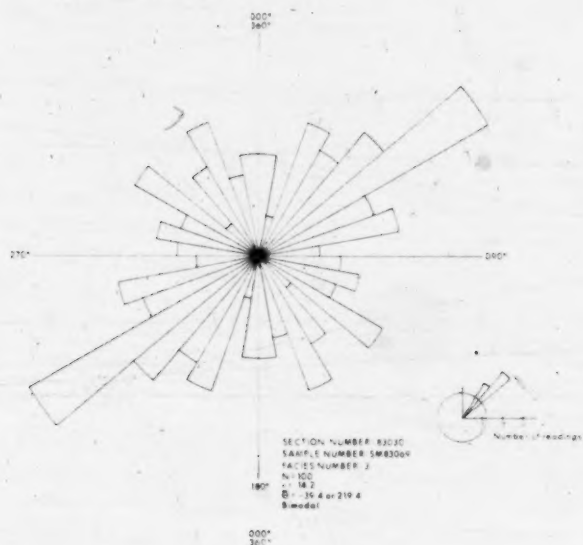


Figure 22: Rose diagrams for strike orientation of a-b planes measured for elongated pebbles from facies 3.

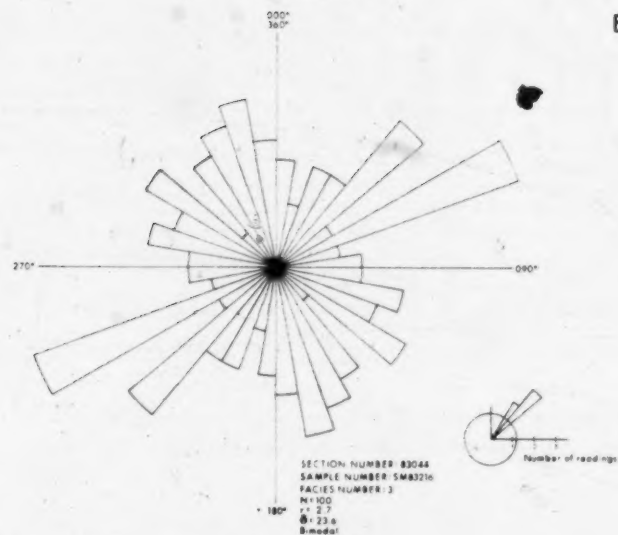
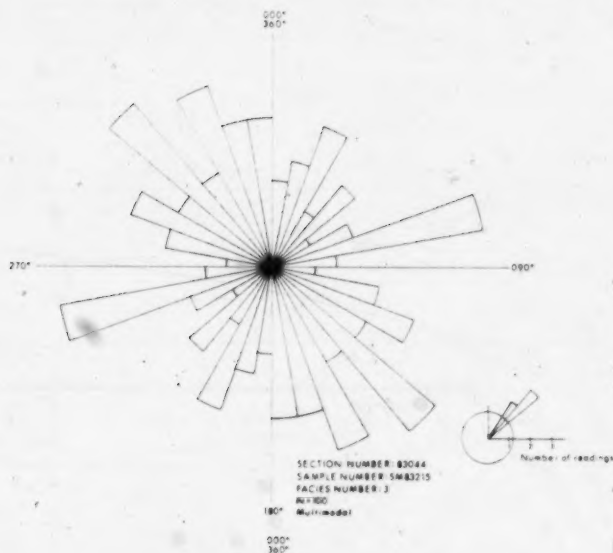
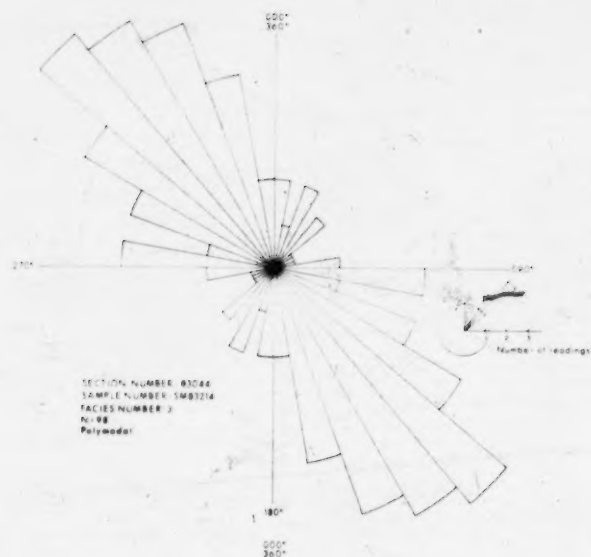


Figure 22: Rose diagrams for strike orientation of a-b planes measured for elongated pebbles from facies 3.

C. DEPOSITIONAL MECHANISMS OF FACIES

FACIES 1

Massive pebbly sand represents fallout deposition (Harms et al., 1982) in channels with high suspended sediment loads. Initial current velocities must have been sufficiently competent to entrain pebbly sand. Progressive sedimentation of this facies would occur as currents velocities decrease.

FACIES 2

Facies characteristics such as very poor sorting, lack of stratification, crude normal grading, and non-erosive bases suggests sedimentation through mass emplacement (Harms et al., 1982; Nemec and Steel, 1984; Krapez, 1985). This facies is always found along valley walls proximal to tributary stream channels, and is associated with steeper slopes. The abundance of coarse, angular boulder clasts indicates a local gravel provenance which is not common in other White Channel gravelly facies. The above observations suggest that massive gravel was deposited as sediment gravity flows, which moved

downslope tranverse to the trend of the main valley axis. Such flows may have been sandy debris flows which were initiated by seasonal discharge runoff on unstable, weathered slopes. Normal grading in this type of sediment gravity flow is developed as denser particles settle directly from suspension, while modal gravel clasts are emplaced at higher levels which were achieved during the flow event (Nemec and Steel, 1984). This forms a basal lag, and an overall normal grading of gravel clasts in the flow unit.

This facies also occurs as bedded sequences of several flow events separated by gradational contacts and discontinuous clayey beds which contain granule to fine pebble clasts. These interbeds of "diamict" are interpreted to represent shear zones which form the channellised or erosive component of the flow.

FACIES 3

Crudely stratified gravel is found throughout the entire White Channel sequence and is difficult to interpret. Facies characteristics such as poor sorting, coarse texture, dominant a-axis flow parallel and a-axis imbrication, and scattered fabric patterns suggests deposition in the form of gravelly

sediment gravity flows. However, several workers have described fluvial deposits such as braid bars to be internally massive to crudely planar stratified (Eynon and Walker, 1974; Miall, 1977, 1978; Hein, 1984; Smith, 1985). Also, low relief channel features such as diffuse gravel sheets may develop crude horizontal stratification (Hein and Walker, 1977; Hein, 1984). Low relief channel features and braid bar deposits should have distinct a-axis flow tranverse, b-axis imbrication upstream if the gravelly sediment is coarse and transported as bedload (Hein, 1984). Only saltating and pivoting smaller clasts in channels will have a-axis flow parallel, a-axis imbricate patterns (Hein, 1984). Thus, development of a-axis imbrication in stream deposited crudely stratified gravel is possible only if current velocities have the ability to rework bedload sediment. As previously discussed crudely stratified gravel is coarse-grained and imbrication types range from 60 to 70 % a-axis upstream, and 30 to 40 % b-axis upstream. This implies that in a channel setting current velocities would be very high such that limited bedload transport and reworking of coarse clasts is possible. However, strong current velocities should produce preferred pebble

orientations, and the strike frequency patterns show a wide range of distributions (Figure 22).

In summary, observed clast imbrication types in coarse-grained crudely stratified gravel favours deposition by either mass emplacement or stream channel sedimentation with very high current velocities. General facies characteristics do not provide conclusive evidence for depositional mechanisms of this facies type. In general stratification and fabric types and patterns in gravel types is poorly understood, and consequently interpretation for the crudely stratified gravel should be regarded as speculative.

FACIES 4

Facies 4 is the result of erosive channel scour during flood conditions. Facies characteristics such as scoured bases, exceptionally coarse gravel clasts and disorganized fabric infers deposition during unusually high discharge intervals. In addition, the gravel clasts have a "clustered" appearance. Cluster bedforms are the result of stoss and wake deposition around large clasts (Brayshaw, 1984). This type of deposition occurs when a large clast becomes an

obstacle which disrupts flow patterns, and traps finer particles which are moving by saltation (Brayshaw, 1984). The initiation of cluster formation begins during flood conditions when exceptionally large clasts are moved by traction. Infilling of the cluster bedform occurs during falling stage from flood levels (Brayshaw, 1984), when finer suspended particles are trapped. The high muddy matrix content of this facies type is also the result of suspended sediment settling out after gravelly deposition with falling discharge levels.

FACIES 5

Assuming finer sediment is available, openwork gravel is the result of sporadic discharge levels with current velocities high enough to maintain finer sediments in suspension (Smith, 1985).

FACIES 6

This fine muddy facies represents deposition of suspended sediment during waning discharge levels in local depressions and on bar surfaces (Smith, 1985). Convolute beds and loaded bases are the result of

rapid deposition of overlying coarser gravelly sediments (Reineck and Singh, p.79). The abundant organic detritus, and oxidized lenses of fine sand indicate subaerial exposure at some time prior to burial.

FACIES 7

This stratified facies represents sedimentation on flat or planar surfaces, with current velocities high enough to move pebbly sand as bedload sediment. This type of sedimentation may occur in channels or on bars if discharge levels are relatively uniform such that reworking is possible.

FACIES 8

This well sorted and distinctly stratified gravelly facies is one of the most abundant facies types found in the White Channel deposit. The distinct planar stratification and well defined b-axis imbrication suggests gravelly bedload sedimentation on a relatively horizontal surface. These bedforms probably represent well developed low relief bar deposits and/or diffuse gravel sheets in

main channels. The polymodal strike frequency pattern (Figure 21) for this facies may also indicate bar form sedimentation, as channel deposition generally has less scattered clast fabrics (Hein, 1984).

FACIES 9

Facies 9 also represents gravelly bedform sedimentation under high discharge conditions. The openwork texture is the result of finer sediment (if available) being transported in suspension by high current velocities. Pockets of matrix-filled gravel indicate either fluctuating discharge conditions or clogging of gravel pockets during aggradation under decreased flow conditions (Frostick et al, 1984; Smith, 1985).

FACIES 10 and FACIES 11

These trough cross-bedded pebbly sand and fine gravel facies are channel deposits which formed as a result of migrating large-scale three-dimensional ripples or dunes (Harms et al; 1975, 1982). This type of tractional bedload transport requires competent flow and high velocity flows.

FACIES 12 and FACIES 13

These cross-bedded facies are coarse-grained gravelly facies which have a mean clast size of approximately 10 cm and maximum clast sizes of 28 cm and 18 cm respectively. The term "scoop-shaped" cross-bedding is used for these facies types because it is unlikely that bedload transport in the form of three-dimensional large-scale ripples are responsible for bedding in such coarse gravel. These cross-beds are not "typical" in terms of depositional processes. Tractional transport in the form of three-dimensional ripples or dunes is poorly understood for gravelly sediments. Fahnestock and Bradley (1973) report that in the Knik River of Alaska dunes formed during flood flows of 236,000 cfs, in gravelly sediment with typical clast diameters of 5.5 cm. This indicates that in order for facies 12 and 13 to develop cross-beds through three-dimensional ripple migration, excessively large flood discharges and water depths would be required. A more reasonable explanation for the formation of these bedforms is cut-and-fill of scour pools in main channels. Scour pools are features which form at the intersection of

two or more channels, and represent areas of gravel erosion and transport (Hein and Walker, 1977). Erosion in these pools could produce tangential, broadly curving reactivation surfaces which aggrade as a result of fluctuating water levels and discharge conditions. The openwork texture of facies 13 indicates fine matrix sediment was retained in suspension during gravelly sedimentation in scour pools.

FACIES 14

Planar tabular cross-bedding in gravelly sediments is interpreted to represent angle-of-repose foreset development on accreting surfaces of active unit bars (Smith, 1985). Gravelly foresets develop in deeper flow depths (ratio of flow depth to grain size is >10 ; Smith, 1985), and in conditions where the rate of aggradation exceeds the rate of progradation (Hein and Walker, 1977). The general lack of planar tabular cross-bedding in the White Channel deposit indicates that flow was generally shallow, and erosion of unit bars was excessive, resulting in low relief features.

CHAPTER V. PALEOENVIRONMENTAL RECONSTRUCTION

A. FACIES SEQUENCES

Tally matrices for Trail and Lovett Hill summarize lateral and vertical facies relationships which occur in the White Channel deposit. These summaries of facies transitions (Tables 4, 5) are derived from measured sections in an up-section direction, and are intended to show basic facies sequences. There is no statistical treatment for these tally matrices due to the low number of observed transitions, and problems with the ability of Markov chain analysis (Miall, 1973) to handle lateral facies sequences and alternating environments (Lowey, 1984). A vertical sequence such as 8 to 3 (6.0 %), would mean that the sequence of facies 3 overlying facies 8 occurs a total of 6.0 % for all observed transitions. The use of proximal, medial and distal for the tally matrices is intended to represent changes in facies characteristics and trends which occur with increasing distance from upstream reference point(s) (Smith, 1985). For example, facies types deposited in upper positions of a rapidly aggraded fluvial system will represent

distal settings as distances and gradients from initial upstream reference points will be changed. A tally matrix for Sourdough Hill was not done due to the lack of transitions.

Trail Hill matrices for section intervals 83035 to 83044 (Table 4) represent facies distributions in the lower or proximal portion of the White Channel deposit. The matrix for vertical transitions shows that the dominant sequence in this proximal position is facies 3 and 4 overlying each other. This occurs a total of 29 times or 44 % of all vertical transitions involve these two facies (Table 4). In addition, minor vertical transitions such as 3 to 8 (9.0 %), 8 to 3 (8.0 %), 8 to 4 (6.0 %), 11 to 4 (4.6 %), and 4 to 11 (4.6 %) occur. Lateral transitions are similar with sequences of facies 3 and 4 occurring a total of 11 times or 35 % of all observed transitions (Table 4). Other lateral facies sequences include 8 to 3 (16.0 %), 3 to 6 (6.0 %), and 10 to 12 (6.5 %).

Trail Hill facies transitions for section intervals 83020 to 83033 and column 83034 (Table 4) represents sequences found in the mid- to upper (distal) positions of the White Channel deposit. The tabulated vertical transitions show that the occurrence of facies sequence 3 and 4 is reduced to a

total of 21 times or is 10.4 % of all observed transitions. The number of minor vertical transitions is increased and is reflective of the complex facies relationships found in distal White Channel sequences. Some of these minor transitions include 8 to 4 (5.0 %), 4 to 8 (5.0 %), 3 to 6 (4.5 %), 6 to 8 (4.5 %), 8 to 3 (4.5 %), and 3 to 8 (3.5 %). The tally matrix for lateral transitions (Table 4) also shows an increased number of minor sequences with no clearly dominant transition type. Laterally, the sequence of facies 3 and 4 occurs a total of 14 times or 12.0 % of all observed transitions. Other minor sequences include 4 to 6 (6.8 %), 6 to 4 (4.3 %), 8 to 6 (6.0 %), 6 to 8 (4.3 %), and 8 to 3 (4.3 %).

The tally matrices for Lovett Hill (Table 5) are also good indicators of vertical and lateral sequences found in mid- to upper positions in the White Channel deposit. The sequence of facies 8 overlying facies 3 (3 to 8 and 8 to 3) occurs a total of 20 times which is 16.0 % of all observed transitions. This forms the dominant vertical facies sequence for Lovett Hill. Minor vertical transitions include 8 to 6 (5.6 %), 8 to 11 (4.0 %), 6 to 3 (4.0 %), 3 to 12 (4.0 %), 12 to 3 (4.0 %), 4 to 3 (4.0 %), and 4 to 8 (4.0 %). The dominant lateral sequence

concur with the vertical observations in that facies 3 and 8 occur a total of 15 times which is 17.8 % of all observed transitions. Other lateral transitions include 6 to 8 (6.0 %), 3 to 12 (4.8 %), 12 to 3 (4.8 %), 11 to 8 (4.8 %), and 3 to 4 (4.8 %).

TABLE 4. TRAIL HILL TALLY MATRIX

Vertical Facies Transitions-Section Intervals 83035 to 83044

s.s.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	total
1	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	X	15	0	1	0	6	0	2	1	2	0	0	27
4	0	0	14	X	0	1	0	0	0	1	3	1	0	0	20
5	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0
6	0	0	2	0	0	X	0	0	0	0	0	0	0	0	2
7	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0
8	0	0	5	4	0	0	0	X	0	0	0	0	0	0	9
9	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0
10	0	0	0	2	0	0	0	0	0	X	1	0	0	0	3
11	0	0	0	3	0	0	0	0	0	0	X	0	0	0	3
12	0	0	0	1	0	0	0	0	0	1	0	X	0	0	2
13	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0
total	10	0	21	25	0	2	0	6	0	4	5	3	0	0	66

Lateral Facies Transitions-Section Intervals 83035 to 83044

s.s.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	total
1	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	X	6	0	2	0	1	0	1	0	0	0	0	10
4	0	0	5	X	0	0	0	1	0	1	0	1	0	0	8
5	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0
6	0	0	1	1	0	X	0	0	0	0	0	0	0	0	2
7	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0
8	0	0	5	0	0	0	0	X	0	0	0	0	0	0	5
9	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0
10	0	0	1	0	0	0	0	0	0	X	0	2	0	0	3
11	0	0	0	0	0	0	0	0	0	1	X	0	0	0	1
12	0	0	1	1	0	0	0	0	0	0	0	X	0	0	2
13	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0
total	10	0	13	8	0	2	0	2	0	3	0	3	0	0	31

TABLE 4 continued

Vertical Facies Transitions-Section Intervals 83020 to 83033
and Column 833034

s.s.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	total
1	X	0	1	2	0	1	0	0	0	0	0	0	0	0	4
2	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	X	13	0	9	0	7	0	3	2	6	0	1	42
4	1	0	8	X	1	4	0	10	3	2	1	2	1	0	33
5	0	0	0	1	X	0	0	1	0	0	0	0	1	0	3
6	1	0	6	6	0	X	1	9	1	1	1	3	0	0	29
7	0	0	2	1	0	1	X	1	0	0	0	0	0	1	6
8	1	0	9	10	1	11	1	X	3	0	6	1	2	0	45
9	0	0	1	2	0	1	0	3	X	0	0	0	0	0	7
10	0	0	1	0	0	1	0	1	0	X	0	0	0	0	3
11	0	0	1	0	1	1	1	4	2	1	X	1	1	0	13
12	1	0	3	2	0	2	0	1	0	1	1	X	0	0	11
13	0	0	0	2	0	0	0	0	0	0	0	0	X	0	2
14	0	0	0	2	0	0	0	1	0	0	1	0	0	X	4
total	15	0	32	41	3	31	3	38	9	8	12	13	5	2	202

Lateral Facies Transitions-Section Intervals 83020 to 83033

s.s.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	total
1	X	0	0	0	0	1	0	0	0	0	0	1	0	0	2
2	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	X	9	0	4	0	4	0	0	1	1	0	0	19
4	0	0	5	X	0	8	0	4	3	0	1	4	0	0	25
5	0	0	2	1	X	0	0	0	0	0	0	0	0	0	3
6	1	0	2	5	0	X	1	5	1	0	0	2	1	0	18
7	0	0	0	1	0	0	X	0	0	0	0	0	0	0	1
8	0	0	5	1	0	7	0	X	2	0	4	1	1	0	21
9	1	0	0	0	0	0	0	2	X	0	0	0	0	0	3
10	0	0	0	1	0	0	1	0	0	X	0	2	0	0	4
11	0	0	1	0	1	0	0	2	0	1	X	1	0	1	7
12	1	0	0	3	0	2	0	1	0	0	1	X	0	0	8
13	0	0	0	3	1	0	0	1	1	0	0	0	X	0	6
14	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0
total	13	0	15	24	2	22	2	19	7	1	7	12	2	1	117

TABLE 5. LOVETT HILL TALLY MATRIX

Vertical Facies Transitions-Section Intervals 83001 to 83013
and Column 83014

s.s.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	total
1	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	X	3	0	3	1	14	1	1	2	5	0	1	31
4	0	0	5	X	0	2	1	5	1	0	2	3	0	0	19
5	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0
6	0	0	5	0	0	X	0	4	0	0	0	0	0	0	9
7	0	0	2	1	0	0	X	2	0	0	0	0	0	0	5
8	0	0	6	2	0	7	1	X	1	4	5	4	0	0	30
9	0	0	1	0	0	0	0	1	X	0	0	0	0	0	2
10	0	0	1	2	0	0	0	1	0	X	0	0	0	0	4
11	0	0	2	1	0	0	0	2	0	2	X	1	0	1	9
12	0	0	5	2	0	0	0	2	0	0	1	X	0	0	10
13	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0
14	0	0	2	1	0	0	1	2	0	0	0	0	0	X	6
total	0	0	29	12	0	12	4	33	3	7	10	13	0	2	125

Lateral Facies Transitions-Section Intervals 83001 to 83013

s.s.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	total
1	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	X	4	0	2	2	7	0	0	1	4	0	1	21
4	0	0	1	X	0	0	0	3	1	1	1	2	0	1	10
5	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0
6	0	0	2	1	0	X	0	5	0	0	0	1	0	0	9
7	0	0	0	0	0	0	X	3	0	0	0	0	0	0	3
8	0	0	8	2	0	4	1	X	0	1	3	1	0	0	20
9	0	0	1	0	0	0	0	0	X	0	0	0	0	0	1
10	0	0	0	1	0	0	0	1	0	X	0	0	0	0	2
11	0	0	1	0	0	0	0	4	0	0	X	1	0	0	6
12	0	0	4	3	0	0	0	2	0	0	1	X	0	1	11
13	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0
14	0	0	1	0	0	0	0	0	0	0	0	0	0	X	1
total	0	0	18	11	0	6	3	25	1	2	6	9	0	3	84

B. FACIES ASSOCIATIONS

Coarse-Grained Facies

As mentioned previously, 80 % of all beds measured in the White Channel deposit are gravel. The coarse-grained association deals with all of the described gravelly facies and includes 2,3,4,5,8,9,11,12,13 and 14.

A general trend for White Channel gravelly sediment is to be coarser-grained and less organized toward the base, and finer-grained with improved sorting and stratification up-section. Basal or proximal vertical facies associations are characterized by crudely stratified and chaotic gravel (i.e. 3 to 4 and 4 to 3). Both are poorly sorted, and represent types of channel deposition and/or mass flow deposition. The poor sorting indicates that considerable sediment was being transported during initial phases of White Channel sedimentation. The crudely stratified gravelly facies represents either deposition by mass emplacement or sedimentation in stream channels with high flow velocities. The chaotic gravelly facies is interpreted as an erosive channel scour which formed

during flood conditions. Features such as cluster bedforms and high matrix content indicate flooding was followed by rapidly waning flow. This proximal association suggests that peak discharge levels and flood-type flow velocities were present during initial phases of White Channel sedimentation. Flow velocities were sufficient to transport exceptionally large clasts during initial stages of cluster bedform development. Thus, it is reasonable to conclude that proximal White Channel discharge levels and flow velocities were high enough to tractionally deposit and rework crudely stratified gravel in channels. This type of stream sedimentation may explain the dominant a-axis imbrication type associated with crudely stratified gravel. Minor proximal vertical associations include the sequence of distinctly stratified gravel with crudely stratified gravel and chaotic gravel (i.e. 3 to 8, 8 to 3, and 8 to 4). Facies 8 is interpreted to represent low relief barforms (i.e. longitudinal bars) or diffuse gravel sheets in main channels. This indicates limited development of unit bars in association with poorly sorted channel deposits during early stages of White Channel sedimentation. Also, the minor association of chaotic gravel and trough cross-stratified pebbly

gravel (i.e. 11 to 4 and 4 to 11) indicates that development of dunes in channels occurred after flood events. Lateral associations in the proximal setting agree with vertical sequences in that channel deposition dominated White Channel processes (i.e. 3 to 4). Other lateral sequences associated with channel deposition (crudely stratified gravel) include: 1. barform sedimentation of distinctly stratified gravel (i.e. 8 to 3); and 2. development of channel structures such as cross-beds from large-scale three-dimensional ripples, and scours in pools.

Facies associations in the mid- to upper portion of the White Channel sequence show a great deal of variability. Proximal vertical associations such as crudely stratified and chaotic gravel (i.e. 3 to 4) overlying each other are reduced in occurrence. Distinctly stratified gravel is vertically associated with crudely stratified gravel (i.e. 8 to 3 and 3 to 8), and chaotic gravel (i.e. 8 to 4 and 4 to 8). This indicates that medial to distal positions of the White Channel sequence are characterized by well developed barform and channel sedimentation (facies 8), which is overlain by both high discharge and flood-type channel deposits (facies 3 and 4).

Laterally, the facies trends agree with vertical observations, and also indicate that barform and channel sedimentation is the dominant process. In addition, Lovett Hill vertical and lateral transitions show that trough cross-bedding in shallow channels occurs above bar deposits (i.e. 8 to 11 and 11 to 8), and scoop-shaped cross-bedding occurs in deeper channels and pools (i.e. 3 to 12, and 12 to 3).

Facies 2 is a coarse-grained, massive to crudely normally graded gravel which was deposited by mass emplacement as a sandy debris flow. Good examples of this facies are found at Sourdough Hill (Appendix C; column 84013). There are few facies transitions associated with valley marginal sediment flows. However, column 84013 shows that stratified sand (facies 7), planar cross-stratified pebbly sand and gravel (facies 14), and laminated mud and fine sand (facies 6) is found associated with gravity flow sequences. This indicates that stream channel deposition occurred between flow events, and the planar cross-beds may represent the paleosurface of a valley marginal setting.

FINE-GRAINED ASSOCIATION

The fine-grained association is a minor component of the White Channel deposit, and includes facies 1, 6, 7, and 10. All of these facies represent deposition on bars or in channels during decreasing or fluctuating discharge levels.

Lower or proximal White Channel sequences generally lack these facies, however there are some minor associations. For example, laminated mud and fine sand is laterally associated with crudely stratified gravel (i.e. 3 to 6). This occurs only a total of 6.0 % of all observed basal facies (Table 4), and represents deposition of suspended sediment during waning discharge levels. Other types of processes associated with proximal channel deposits includes large-scale three dimensional ripple or dune migration (i.e. 3 to 10, 4 to 10, 10 to 4, and 12 to 10).

Medial and distal positions in the White Channel sequence are characterized by an increase in the occurrence of fine-grained facies with gravelly sediments. Laminated mud and fine sand (facies 6) is associated with facies 3, 4, 8, 9, 11, and 12. These lateral and vertical associations do not form a high

percentage of transitions. However the regular occurrence of facies 6 with the majority of coarse-grained facies shows that overbank-type sedimentation was widespread yet locally distributed according to channel migration and lower flow velocities. Other fine-grained processes in channels and on bars includes planar bed flow (i.e. 3 to 7, 4 to 7, 8 to 7), and large-scale three dimensional ripple migration (i.e. 3 to 10, 10 to 4, and 8 to 10).

In summary, the coarse-grained facies association is characterized by proximal high flow velocity channel sequences, and medial to distal barform deposition with channels. Minor facies associations are components of bars and channels in the form of bedform development under various flow levels (Table 6). Valley marginal gravity flows (facies 2) form independently of major gravelly facies, and thus are unique components in the White Channel sequence.

The fine-grained facies association is primarily deposition of muddy sediments in gravelly channels and on bar tops as a result of decreasing discharge levels associated with channel and bar abandonment.

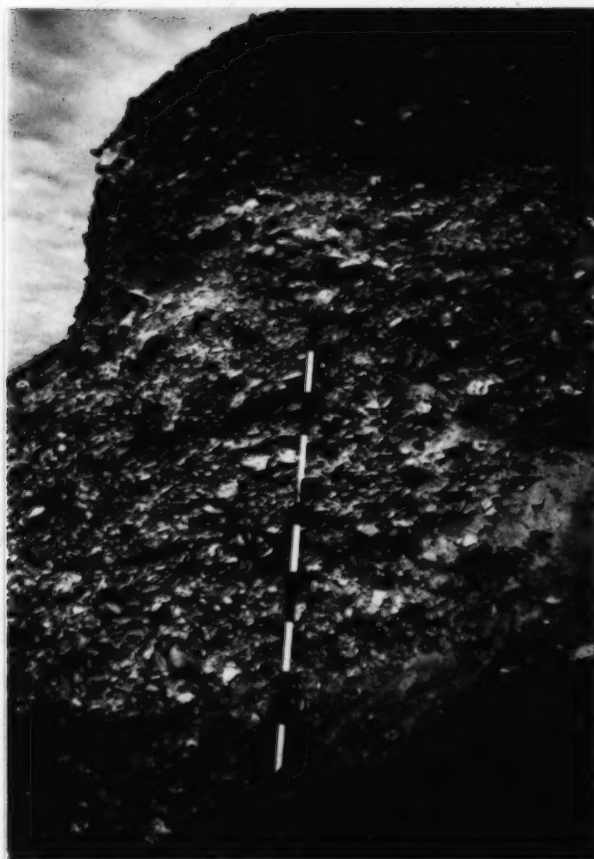


Plate 23. Stacked sequence of crudely stratified gravel. This typifies proximal or lower White Channel sedimentation.

TABLE 6 SUMMARY OF WHITE CHANNEL FACIES ASSOCIATIONS

ASSOCIATION NAME	MAJOR FACIES TYPES	MINOR FACIES TYPES	DEPOSITIONAL ENVIRONMENTS
Coarse-grained facies	3, 4, 8	2, 5, 9, 11, 12, 13, 14	Lower or proximal sedimentation is represented by channel sequences of crudely stratified and chaotic gravel (3, 4). These deposits form under high discharge and flood conditions. Mid- to upper (distal) sedimentation is dominated by bar deposits or distinctly stratified gravel (8), in association with channel deposits of crudely stratified and chaotic gravel. Associations of minor facies are components of bar and channel settings, and represent bedform sedimentation under varying discharge levels. Coarse, massive gravelly beds (2) are sediment gravity flows which form independently of major gravelly facies.
Fine-grained facies	6	1, 7, 10	Deposition of muddy and sandy sediments (6) increases up-section, and is overbank-type sedimentation associated with waning flow and channel abandonment. Minor facies represent types of bedform sedimentation in gravelly channels.

C. IDEALIZED VERTICAL SEQUENCES AND PALEOGEOGRAPHIC MODEL

Idealized vertical columns for the White Channel deposit are divided into proximal and distal sequences (Figure 23). They represent components of a braided river environment (Figure 24) which have distinct differences in facies distributions and trends from lower (proximal) to middle (medial) and upper (distal) positions.

As previously discussed, lower or proximal facies sequences are typically interbedded poorly sorted channel deposits which were formed during peak and flood discharge intervals (Figure 23). Also, limited development of bar deposits, low relief channel features (i.e. diffuse gravel sheets) and bedform sedimentation (channel scour, dunes) in both deep and shallow channels form components of the proximal setting. This shows that the initial White Channel environment was crudely braided with various types of channel systems and scattered low relief barforms. Medial and distal settings comprise the majority of White Channel deposit, and are characterized by increased complexity in facies trends (Figure 23). It appears that low relief unit bar sedimentation in

association with main channel features such as diffuse gravel sheets, and peak discharge channels characterize distal settings. Lenticular muddy beds cap both bar and channel deposits regularly and forms crude depositional cycles which indicates lateral migration and abandonment of channels. Thus, the aggradational phase or medial to distal White Channel sedimentation was characterized by low relief unit bar development in a multi-channelled braided environment (Figure 24).

In addition to the main valley braidplain setting, subaerial gravelly mass flows were deposited as either components of tributary alluvial fan sequences, or valley wall gravity flows (Figure 24). The massive gravelly facies is interpreted to represent sandy debris flows which are thought to be part of a tributary alluvial fan deposit because they are usually stacked sequences, and are associated with stratified fluvial sediments.

The idealized vertical sequences (Figure 22) for proximal and distal White Channel sedimentation do not fit into one particular type of vertical braided river model by Miall (1977, 1978). This is due to the problem of comparing White Channel vertical sequences with Miall's over-simplified facies scheme. For

example, the Scott model is dominated by facies Gm (massive or crudely bedded gravel) which is interpreted to represent longitudinal bars, lag deposits, and sieve deposits (Miall, 1978). Facies Gm is represented in the White Channel sequence by massive, chaotic, crudely stratified, and distinctly stratified gravel (facies 2,3,4 and 8). Each of these White Channel gravelly facies are physically and depositionally distinct. Thus, it is difficult to know if Miall's facies Gm includes some of the processes associated with the above White Channel gravelly facies. However, proximal White Channel sequences roughly correspond to the Scott-type model as both have facies which represent channel deposition. Distal White Channel sequences are characterized by barform and channel deposition with some crude cycles shown by muddy overbank sedimentation. These features are found in both Scott and Donjek-type vertical models.

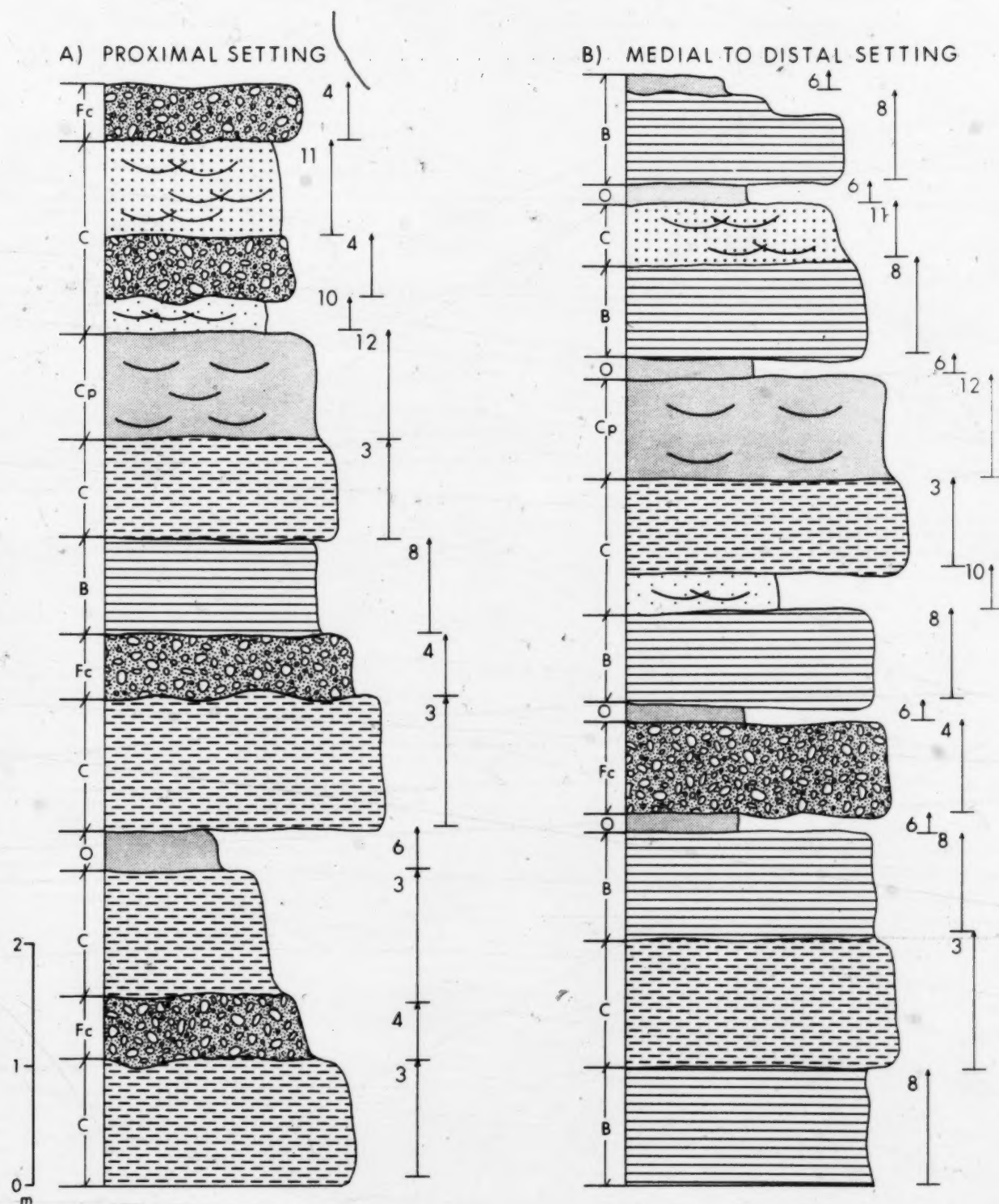
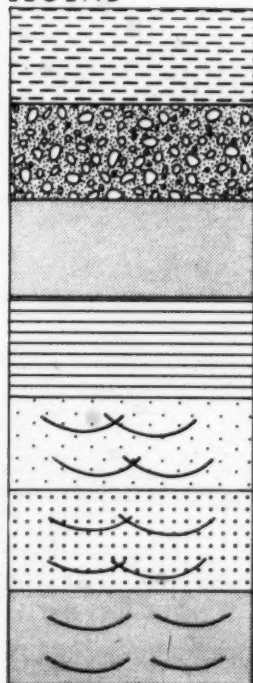


Figure 23: Idealized White Channel Vertical Sequences

LEGEND



Facies 3: Crudely stratified gravel

Facies 4: Chaotic gravel

Facies 6: Massive to laminated mud and fine sand

Facies 8: Distinctly stratified gravel

Facies 10: Trough cross-stratified pebbly sand

Facies 11: Trough cross-stratified gravel to pebble gravel

Facies 12: Scoop-shaped cross-stratified gravel

6 8
 |—————> Facies transitions

Depositional Settings:

C - channel

Cp - channel pool

Fc - flood channel

B - bar

O - overbank

Figure 23 cont.

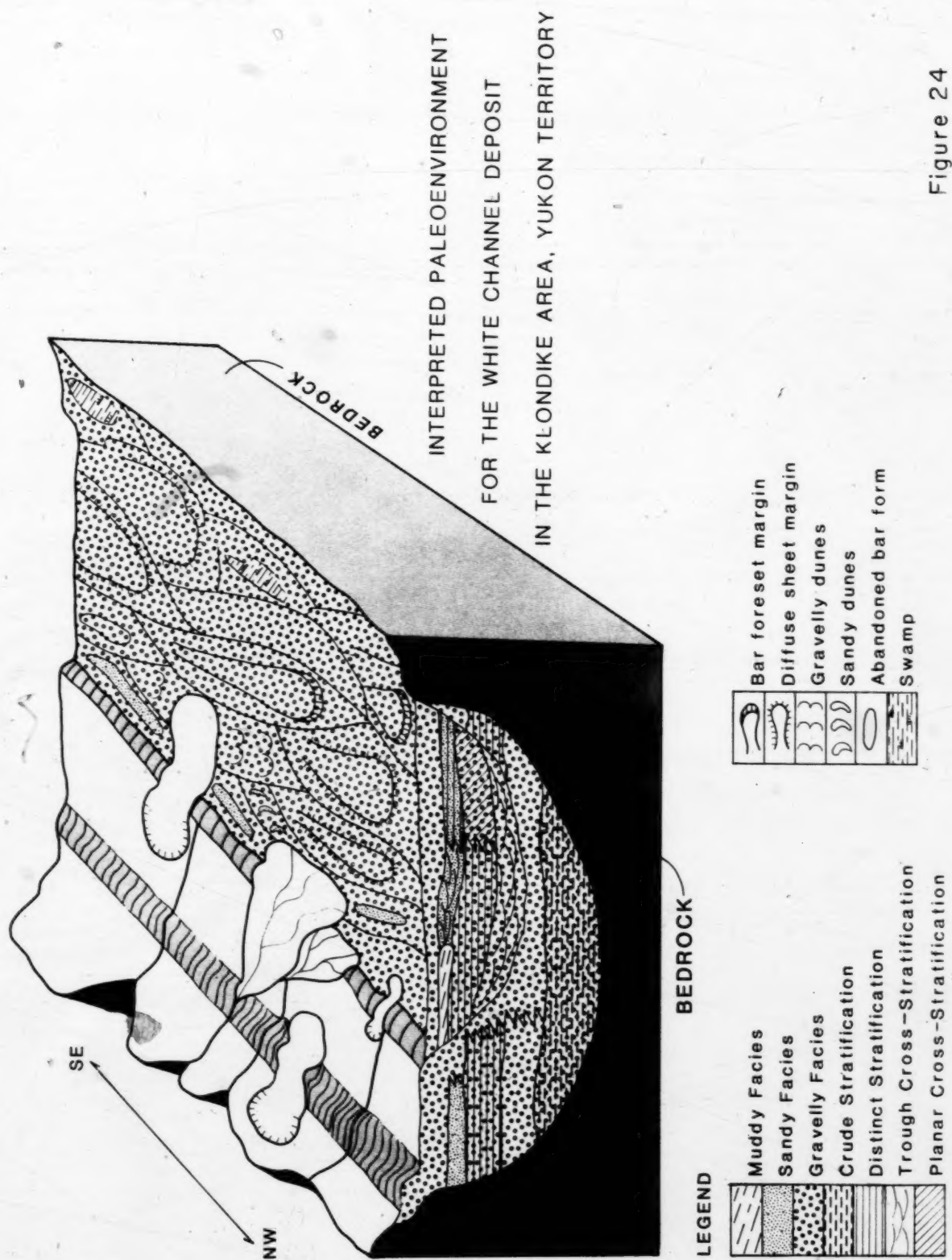


Figure 24

CHAPTER VI. WHITE CHANNEL MINERALIZATION

A. GOLD DISTRIBUTION AND PLACER SETTINGS

Lithofacies types were sampled on an individual basis for heavy mineral and placer gold content. The purpose of this sampling scheme was to determine the facies-related distribution of gold by identifying which facies types consistently contain gold. Determination of gold concentration levels or grade for individual facies types was not possible with this limited sampling program. A total of 27 samples were taken (see Appendix C) and processed for gold and related heavy minerals.

The greater concentration of gold in the White Channel sequence is reported to be in the lower 4 to 6 feet above the bedrock surface (McConnell, 1907). Mining activities and exploration programs confirm that gold concentration is greatest near the bedrock surface, and generally decreases up-section.

Sampling has shown that placer gold is found in virtually all of the gravelly facies in the White Channel sequence. Sedimentologically this is possible as each facies represents a depositional environment which has the ability to concentrate heavy minerals. For example, fully developed convergent stream flow

concentrates heavy minerals by selective entrainment (removal) and transport of mineral populations with similar specific gravities (Smith, 1983; Slingerland, 1984). Convergent stream flow forms in shallow channels during peak discharge intervals or in channels with width restrictions. White Channel facies which formed in channels with turbulent, convergent flow include proximally deposited crudely stratified and chaotic gravel (facies 3 and 4). Concentration levels for heavy minerals in this type of convergent flow is expected to be low as peak discharge levels are short-lived, and time for sorting is minimal. The high percentage of matrix sediment in crudely stratified and chaotic gravel indicates that suspended sediment levels were high during sedimentation. It also indicates that suspension sorting (Slingerland, 1984) probably played an important role in concentrating finer-grained heavy minerals in matrix sediment as flow became more divergent with decreasing discharge levels. Another type of convergent flow associated with aggraded channel lag deposits (facies 3) is generated in "sluiceways" (Smith, 1983) created between stable banks and bars. This type of convergent flow is not as discharge dependent because high stream velocities

and turbulent flow is created as a result of width restrictions. Medial to distal White Channel sequences are characterized by unit bar deposits in lateral association with channel deposits (i.e. 8 to 3). Thus, creation of convergent flow in constricted sluiceway channels between low relief bars was part of the medial to distal braided environment. This type of convergent flow favours selective entrainment and transport sorting, and concentration of heavy minerals should be high as convergent flow is not totally dependent upon fluctuating discharge levels. Convergent flow at the bedform level also concentrates heavy mineral particles by entrainment and transport sorting when active tractional bedload transport moves particles at varying stream velocities and depths. Channel and bar deposits which have developed distinct bedforms and concentrated placer gold include trough cross-stratified pebbly sand and gravel (facies 10, 11), scoop-shaped cross-stratified gravel (facies 12, 13), and planar cross-stratified gravel (facies 14). Placer gold is also found in distinctly stratified gravel (facies 8) which represents low relief unit bars. These bar deposits have concentrated heavy minerals particles through entrapment during bedload sorting and

aggradation. It is also important to note that gold presence in gravelly facies types varies from bed to bed. This is due to the variable and transitory nature of local gold sources (Smith and Minter, 1980) in gravelly sediment. Point sources in stream gravels are not pervasive, and stream hydraulics may be ideal for heavy mineral concentration but the local source may be missing. Thus, two identical sedimentary beds may have totally different heavy mineral concentrations (Smith and Minter, 1980).

Placer gold is also found in massive gravelly sequences (facies 2) which are interpreted as sediment gravity flows. Concentration and sorting of heavy minerals in gravity-induced deposits is related to the downward migration of particles during movement. This type of shear and suspension sorting (Slingerland, 1984) is also responsible for the crude normal grading which is characteristic of this facies type. Gold mineralization in this type of colluvial placer deposit indicates that bedrock source areas must be locally derived and exposed.

In summary, concentration of placer gold in proximal White Channel sequences is related to converging flow patterns in aggraded channel lag and flood deposits. Medial and distal White Channel

sequences have placer gold concentrated in channel deposits where sluiceways were formed, and in bar deposits which trapped heavy mineral particles during aggradation. Cross-stratification throughout the entire White Channel sequence in both bar and channel deposits also concentrated placer gold by high stream velocities and convergent flow patterns. Valley marginal gravelly mass flow deposits also concentrate placer gold through shear and suspension sorting processes during the development of normal grading.

The overall distribution of placer gold in the White Channel deposit is discontinuous, with auriferous facies occurring throughout the entire deposit. There is no consistent pay streak on the bedrock surface, but rather an apparent increase in the number of proximal facies which contain placer gold. Concentration processes become more efficient up-section where sorting improves as a result of bar and channel systems. Thus, the increased number of proximal channel deposits which contain gold must be related to an increase of gravelly point sources proximal to initial lode sources. Local point sources for concentration of heavy minerals decrease up-section, presumably as initial lode sources are depleted. This agrees with Krapez (1985) in that

distribution and grade of local gold sources appears to control facies mineralization. Thus, sedimentary concentrating mechanisms in a placer deposit may be of secondary importance for both distribution and grade of the resultant mineral deposit

B. COMMENTS ON GOLD SOURCES IN THE KLONDIKE

Bedrock sources of placer gold have been largely attributed to erosion of quartz veins in the Klondike Schist (McConnell, 1907). In addition, mineralization in quartz-barite veins, quartz veins in the chloritic phase of the Klondike schist, quartz veins in shear zones, pyritic graphitic schist, and paleoplacers have been suggested as lode sources in the Klondike area (Gleeson 1970; Boyle, 1979). Milner (1976) and Debicki (1984-85) document several specific mineral occurrences in the Klondike area, and indicate that volcanic rocks, quartz veins in Klondike schist, and ultramafic rocks are responsible for lode gold mineralization. Debicki (1985) also indicates that gold-bearing mesothermal quartz veins and Late Cretaceous to early Tertiary volcanic rocks are spatially related to structures such as thrust faults, which may have acted as conduits for migration of gold-bearing fluids.

Sedimentology of the White Channel sequence shows that sorting and concentration levels improve up-section. Consistent erosion of auriferous quartz veins in regional country rock (i.e. Klondike Schist) during White Channel aggradation should lead to a

relatively uniform distribution of local point sources in gravelly facies. This would produce a placer deposit with increased concentration levels up-section where sorting mechanisms are more efficient. However, as discussed previously gold values are greatest in lower or proximal White Channel facies near the bedrock surface. Thus, local and discontinuous lode sources must have been available for proximal White Channel erosion and sedimentation. These lode sources must also be of high grade for poorly sorted proximal gravelly facies to contain significant gold values. Lower gold values in distal gravelly facies which show improved sorting indicate decreased point sources of gold available for placer concentration. Thus, erosion of regional country rock seems unlikely as a source for Klondike gold. Scattered distribution of volcanic rocks and known occurrences of local epithermal-type mineralization (Debicki, 1985) appears to "fit" the type of lode source responsible for the distribution of placer gold in the White Channel gravelly sequence. Furthermore, the evidence of hypogene alteration (DuFresne et al, 1985) in White Channel sediments demonstrates epithermal activity. However, the relationship of fluid migration and gold

mineralization in altered White Channel sediments is not understood. Epithermal mineralization in scattered occurrences of volcanic rocks has not been an exploration target in the Klondike area. This may explain why there is no relationship between mineral occurrences relative to the amount of gold extracted from placer deposits in the Klondike area.

CHAPTER VII. CONCLUSIONS

White Channel placer deposits in the Klondike area were formed in a braided environment during Pliocene-Pleistocene uplift of the Klondike Plateau. The interpreted braided environment has the following major components:

1. A main valley proximal setting which was crudely braided with different types of channel systems and scattered unit bars. Major facies sequences are interbedded crudely stratified and chaotic gravel with high matrix contents and poor sorting. These facies were deposited under fluctuating peak and flood discharge levels. These gravelly facies represent types of channel systems uniquely different from well developed channels with low relief features such as diffuse gravel sheets. Exceptionally high discharge levels and flow velocities are required to develop facies characteristics such as cluster bedforms and a-axis imbrication in these types of channel systems.

2. Main valley medial to distal settings which form well defined braided sequences of channels and low relief unit bars. Lateral facies trends become complex and variable in upper White Channel

positions. Major facies sequences include distinctly stratified gravel in association with crudely stratified and chaotic gravel. Lack of planar cross-stratified gravel indicates that water depths were shallow, and erosion of unit bars was high. Lenticular beds of massive to laminated mud and fine sand cap many of the bar-and-channel sequences which forms crude depositional cycles.

3. Valley marginal subaerial gravelly mass flows which are interpreted as sandy debris flows. These mass flows were deposited in association with tributary alluvial fan sequences or as valley wall gravity flows. Diagnostic facies characteristics include very poor sorting, massive structure and crude normal grading.

In a general sense the White Channel sequence has improved sorting and stratification up-section. The facies trends and sequences do not fit one particular depositional model for braided environments. This is probably due to the fact that braided river models are largely based on proglacial outwash environments. White Channel deposition was in a northern nonglacial environment. It follows that both sedimentation and discharge characteristics will differ from those in a proglacial environment.

Placer gold is found in all White Channel gravelly facies. Concentrating mechanisms and sorting processes become more efficient up-section. If point sources of gold were pervasive throughout the entire White Channel sequence gold content would increase up-section. It is known however, that gold content is greater in lower or proximal gravelly facies. This indicates that lode sources must have been local and of high grade in order for proximal gravelly facies to contain significant gold values. Therefore, scattered occurrences of volcanic rocks and epithermal-type mineralization is favoured over metamorphic country rocks as a probable lode source for White Channel placer gold. Also, the presence of hypogene alteration products in White Channel sediments and underlying bedrock confirms that epithermal processes have been active in the Klondike area.

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APPENDICES

A. FIELD TEXTURE (10 LARGEST CLASTS)

Section #	Sample #	Facies	10 Largest Measurements	Maximum	Mean
83001	SM83001	3	33.0,41.5,35.6,37.8,22.0,18.4	41.5	31.4
	SM83002	4	25.5,19.5,22.0,24.2,26.4,16.7,19.2,21.6,15.3,18.4	26.4	20.9
83002	no number	4	25.0,22.0,70.0,35.0,22.0,25.0,19.0,18.0,24.0,18.0	70.0	27.8
83004	SM83134	12	10.0,09.8,13.7,10.0,14.5,11.5,08.9,11.6,27.5,18.1	27.5	13.6
	SM83135	12	11.4,10.0,13.1,08.7,08.7,12.3,10.1,14.2,09.7,12.1	14.2	11.0
	SM83136	8	07.1,06.4,09.5,08.0,07.8,06.9,11.0,09.6,09.8,08.0	11.0	8.4
83005	SM83137	12	15.2,11.7,14.5,10.1,16.3,11.5,19.5,27.1,20.0,11.3	27.1	15.7
	SM83138	11	06.0,09.9,04.5,04.7,05.8,05.7,08.0,05.5,08.2,05.3	9.9	6.4
	SM83141	3	09.1,11.6,13.2,17.4,15.3,12.8,13.4,11.5,08.2,09.7	17.4	12.2
83006	SM83143	3	10.2,09.8,10.2,17.1,10.7,10.3,10.0,09.1,15.4,12.0	17.1	11.5
	SM83145	8	08.2,08.9,09.2,13.9,08.1,07.2,08.9,08.8,08.5,09.0	19.2	10.1
83007	SM83148	8	21.8,14.4,12.2,11.3,13.0,15.9,12.7,11.1,10.5,12.8	21.8	13.6
	SM83149	8	08.2,08.9,12.6,07.0,11.5,06.5,07.6,11.1,11.7,10.1	12.6	9.5
	SM83151	4	09.4,13.0,10.2,22.8,28.2,12.6,15.8,12.5,13.1,19.1	28.2	15.7
	SM83153	3	27.4,13.5,20.2,15.4,31.5,11.6,11.1,09.9,12.0,09.8	27.4	16.2
83008a	SM83155	8	17.2,14.4,17.0,18.1,11.3,27.8,27.6,14.1,12.0,13.6	27.8	17.3
	SM83157	3	13.7,13.7,14.6,14.9,16.3,15.0,17.5,16.6,19.0,13.7	19.0	15.5
83010	SM83165	14	09.3,08.2,07.4,07.6,08.1,07.4,07.0,07.1,06.6,07.0	9.3	7.6
	SM83166	4	06.0,06.3,07.0,06.0,08.6,09.2,09.4,11.1,09.1,09.4	11.1	8.2
	SM83167	8	12.6,11.9,09.7,08.1,11.0,08.5,09.8,09.1,07.2,08.5	12.6	9.6
83011	SM83168	8	14.8,15.2,12.0,10.1,11.2,11.1,10.5,10.1,09.3,09.7	15.2	11.4
	SM83169	8	10.5,10.3,06.2,07.0,06.1,06.3,08.5,08.0,08.4,06.0	10.5	7.7
	SM83170	8	08.9,10.1,11.1,13.4,13.1,	13.4	11.2

83012	SM83171	14	13.3,10.4,10.5,11.6,09.3 08.6,06.2,08.7,06.0,05.9, 06.0,05.0,05.5,06.9,10.4	10.4	6.9
	SM83172	3	14.0,09.5,09.9,11.5,10.3, 12.5,16.5,09.5,15.4,11.1	16.5	12.0
	SM83173	3	25.4,17.2,08.5,12.6,11.7, 13.8,09.6,07.8,08.1,11.7	25.4	12.9
83014	SM83174	8	06.6,10.1,11.9,10.0,06.8, 07.6,06.4,06.6,06.5,06.4	11.9	7.9
	SM83175	8	15.6,10.2,10.1,15.1,12.2, 09.3,10.2,08.2,10.6,28.1	28.1	13.0
	SM83176	9	10.0,05.4,05.4,09.0,12.3, 17.3,07.5,07.4,05.4,06.1	17.3	8.6
83015	SM83177	8	11.6,13.4,11.8,12.8,14.3, 10.6,13.0,12.1,19.7,12.3	19.7	13.2
	SM83196	4	11.7,11.1,09.9,12.0,13.6, 13.6,12.5,17.6,20.2,19.7	20.2	14.2
	SM83197	8	13.4,14.4,14.6,20.1,11.2, 10.1,11.4,12.2,10.3,09.8	20.1	12.8
83020	SM83199	8	16.1,18.4,13.5,10.7,11.3, 10.1,10.4,13.9,10.8,12.5	18.4	12.8
	SM83016	8	08.8,09.4,07.1,10.7,07.8, 10.6,11.6,12.0,07.9,09.1	12.0	9.5
	SM83017	8	08.0,08.5,10.1,08.1,07.4, 12.5,10.4,16.3,13.4,10.8	16.3	10.6
83021	SM83018	8	13.7,11.4,09.5,10.0,10.3, 08.1,07.0,08.0,07.0,06.5	13.7	9.2
	SM83019	3	16.5,15.2,13.8,08.7,07.9, 07.5,10.2,13.6,10.0,10.9	16.5	11.4
	SM83021	4	12.5,12.7,18.7,09.1,08.1, 10.0,11.1,14.3,10.5,15.2	18.7	12.2
83022	SM83022	8	09.7,16.8,10.8,15.2,10.6, 12.4,14.0,13.6,12.6,08.3	16.8	12.4
	SM83023	8	13.7,14.7,11.3,14.5,11.4, 17.8,11.2,12.4,10.8,12.0	17.8	13.0
	SM83024	9	01.4,05.8,06.8,05.5,09.8, 09.5,12.0,06.7,05.6,06.5	9.8	7.0
83022	SM83025	9	07.8,08.9,10.2,11.1,08.5, 09.3,09.5,10.0,15.4,10.5	15.4	10.1
	SM83218	8	10.3,10.7,11.1,11.3,13.7, 13.9,15.0,14.1,17.7,24.2	24.2	14.2
	SM83027	11	10.1,06.4,05.3,04.6,03.8, 04.2,05.0,07.0,03.5,03.7	10.1	5.4
83022	SM83028	8	10.5,12.7,09.2,13.5,12.6, 12.4,10.9,09.4,08.9,10.1	13.5	11.0
	SM83219	9	03.9,05.0,05.7,06.7,06.1, 06.2,08.7,07.0,06.0,04.8	8.7	6.0
	SM83220	4	07.2,07.5,08.4,09.9,09.9, 08.8,11.1,14.4,17.2,22.3	22.3	11.7
	SM83221	3	04.4,04.9,08.1,06.2,05.6,	9.1	6.3

	SM83222	8	07.0,07.0,09.1,04.4,06.2 16.9,14.1,09.3,09.1,09.7, 11.5,08.8,08.2,08.0,09.0	16.9	10.5
83023	SM83029	-	12.2,09.0,08.5,09.6,08.4, 15.4,07.5,07.9,06.9,08.3	15.4	9.4
	SM83030	8	08.6,09.5,09.6,10.6,16.2, 12.0,10.5,09.3,07.8,07.1	16.2,	10.1
	SM83223	8	17.0,16.0,15.2,08.0,09.5, 11.4,15.5,11.0,14.4,15.7	17.0	13.4
	SM83224	4	16.2,26.2,12.6,14.0,12.0, 13.0,11.2,08.7,09.0,09.2	26.2	13.2
	SM83225	8	05.8,08.0,06.3,06.2,07.6, 08.7,07.5,07.6,08.3,08.9	8.9	7.5
83024	SM83032a	13	07.9,10.4,08.4,07.1,09.6 09.3,07.2,08.7,09.9,07.5	10.4	8.6
	SM83032b	13	09.6,08.7,08.9,10.6,07.5, 09.3,10.9,13.6,07.2,13.0	13.6	9.9
	SM83032c	13	07.4,10.5,14.2,10.1,07.7, 10.8,06.8,07.8,09.1,07.1	14.2	9.2
	SM83032d	13	10.0,15.2,14.1,15.0,13.4, 09.1,16.1,08.9,12.1,12.4	16.1	12.6
	SM83226	5	11.1,10.5,10.8,11.9,11.1, 08.0,08.1,08.8,07.5,07.3	11.9	9.5
83025	SM83037	11	06.5,06.9,12.2,06.8,08.4, 07.3,08.8,07.0,09.7,07.5	12.2	8.1
	SM83038	4	09.9,14.0,12.8,14.7,12.5, 15.6,09.4,09.5,10.2,14.5	15.6	12.3
	SM83227	4	10.2,09.3,18.9,10.9,13.0, 10.9,11.5,13.0,11.1,12.8	18.9	12.2
	SM83228	13	18.1,11.3,10.2,09.0,11.2, 11.1,09.2,07.8,07.9,08.5	18.1	10.4
83026	SM83039	13	15.3,13.4,09.9,12.6,10.1, 10.0,09.0,09.6,10.6,10.6	15.3	11.1
	SM83040	11	06.6,05.5,03.9,05.9,09.4, 04.8,04.3,03.2,03.3,04.5	6.6	4.7
	SM83041	12	04.4,05.9,07.9,05.4,06.9, 08.4,04.4,12.0,07.8,06.2	12.9	6.9
	SM83042	8	32.1,13.3,15.6,15.7,10.7, 09.5,08.7,10.8,08.6,09.5	32.1	13.5
	SM83043a	12	12.6,10.6,13.5,14.8,16.1, 17.1,15.6,12.2,12.3,15.5	17.1	14.0
	SM83043b	12	06.9,06.4,09.6,10.5,09.0, 07.7,07.4,06.7,06.5,06.4	10.5	7.8
83027	SM83044	8	20.6,15.4,16.0,12.6,13.7, 15.1,10.8,12.0,09.3,10.0	20.6	13.6
	SM83045	8	12.3,12.2,10.3,13.2,12.2, 18.5,10.4,10.4,16.8,15.8	18.5	13.2
	SM83046	4	15.2,13.0,12.9,14.0,15.2, 17.0,16.5,14.9,13.1,13.0	17.0	14.5
83029	SM83059	3	09.8,12.9,09.6,09.0,10.7,	24.5	13.2

	SM83060	3	16.9,13.3,24.5,13.0,12.7 10.8,13.8,11.6,10.0,14.5, 10.0,12.1,18.4,16.2,12.0	18.4	12.9
	SM83061s	8	08.6,10.2,09.4,07.2,09.9, 12.8,06.0,06.0,06.3,07.1	12.8	8.4
	SM83061b	8	03.5,03.4,03.6,04.7,03.9, 02.6,03.3,02.9,02.7,02.6	4.7	3.3
	SM83062	3	08.5,10.6,06.5,07.2,09.0, 09.9,13.0,09.2,13.8,09.0	13.8	9.7
	SM83063	12	08.2,08.4,14.5,13.1,09.5, 20.5,10.0,10.5,08.2,09.1	20.5	11.2
	SM83064	4	17.0,08.0,10.1,09.7,15.0, 21.2,09.3,12.0,09.5,10.1	21.2	12.2
	SM83065	4	08.5,12.7,15.2,14.9,13.0, 12.0	15.2	12.7
	SM83066	8	09.8,11.0,07.0,07.8,10.7, 07.9,06.4,10.3,08.8,05.7	11.0	8.5
	SM83067a	14	02.9,03.0,04.2,02.6,02.0, 02.5,02.7,03.2,02.8	4.2	3.0
	SM83067b	14	05.7,08.9,08.3,08.4,08.0, 08.5,09.0,07.0,08.3,18.0	18.0	9.0
	SM83229	8	07.9,06.8,05.0,05.8,07.5, 07.1,05.2,05.5,04.7,04.7	7.9	6.0
83030	SM83068	11	08.0,08.2,07.4,08.9,07.1, 06.0,07.3,05.9,06.5,07.2	8.9	7.3
	SM83069	3	11.7,18.0,16.7,15.8,12.2, 15.2,13.3,13.6,18.9,26.4	26.4	16.2
	SM83070	12	06.9,08.1,10.1,07.2,08.0, 07.5,08.9,09.1,19.7,18.8	18.8	10.4
	SM83071	3	12.2,10.0,08.0,08.6,07.5, 08.1,07.0,07.3,06.1,05.8	12.2	8.1
	SM83230	3	05.2,06.5,04.6,05.0,04.2, 03.2,06.0,05.5,04.0,04.2	6.5	4.8
	SM83231	3	12.1,10.9,09.3,11.2,13.2, 14.6,08.2,13.1,13.8,09.9	14.6	11.6
83031	SM83072	4	11.2,12.1,09.4,12.7,09.6, 14.5,13.0,12.8,16.8,17.2	17.2	12.9
	SM83073	3	13.6,11.2,09.8,11.2,11.1, 12.9,16.0,15.5,12.9,12.0	16.0	12.6
	SM83074a	8	09.4,14.5,09.4,06.1,07.7, 10.6,13.1,17.7,17.9,07.0	17.9	11.2
	SM83074b	8	04.0,07.3,05.0,04.8,03.9, 05.3,05.8,04.2,05.5,03.9	7.3	5.5
83032	SM83075	3	11.4,10.5,13.0,11.3,11.9, 09.6,14.0,08.5,11.8,12.1	14.0	11.4
	SM83076	12	09.0,11.8,09.8,08.5,07.5, 07.1,07.4,07.0,06.8,07.9	11.8	8.3
	SM83232	4	07.3,06.0,06.8,11.5,09.1, 10.1,08.1,06.9,09.0,09.1	11.5	8.4
83033	SM83077	4	13.1,10.8,15.9,08.1,09.9,	19.4	10.7

			10.7,19.4,10.5,09.0		
	SM83078	3	07.3,10.2,09.9,10.6,07.0, 14.8,11.1,09.3,07.4,08.9	14.8	9.7
	SM83079	4	08.7,13.8,13.1,12.0,18.6, 13.1,07.9,09.6,14.8,13.6	18.6	12.5
	SM83233	8	05.5,04.0,07.9,04.6,05.7, 04.7,04.9,05.2,04.6,04.5	7.9	5.2
83035	SM83081a	8	03.1,03.0,03.1,03.7,02.9, 05.0,04.1,04.1,02.5,03.9	5.0	3.5
	SM83082	4	05.7,06.0,04.8,04.9,04.6, 04.3,05.0,04.1,03.9,03.6	6.9	4.7
	SM83083	12	12.5,14.2,06.0,08.3,09.9, 06.4,06.4,05.8,06.1,06.1	14.2	8.2
	SM83084	4	08.9,08.5,09.0,10.2,10.5, 11.2,12.8,15.1,13.0,15.3	15.3	11.5
	SM83085	11	09.5,09.7,10.3,10.0,09.0, 08.9,08.5,07.8,07.9,07.7	10.3	8.9
	SM83087	3	10.8,12.0,16.5,17.5,16.6, 18.3,13.9,13.1,13.5	18.3	13.2
83036	SM83088	4	09.8,15.1,13.2,08.9,10.1, 13.9,10.1,10.2,14.1,12.6	14.1	11.8
	SM83090	4	10.6,11.3,11.0,08.9,16.8, 15.9,11.8,09.2,09.2,11.6	16.8	11.6
	SM83091	3	08.0,12.6,08.7,06.0,08.7, 07.0,04.6,07.2,06.0,05.7	12.6	7.5
	SM83092	4	13.0,08.7,08.8,15.7,10.0, 15.2,09.1,11.2,12.4,12.3	15.7	11.6
83037	SM83093	3	07.5,06.0,04.0,11.5,27.0, 07.0,16.0,18.0,10.0,08.0	27.0	11.5
	SM83094	8	23.0,12.0,11.0,11.0,23.0, 11.5,13.5,10.0,13.0,12.0	23.0	14.0
	SM83095	8	08.0,06.5,07.0,08.0,06.0, 06.5,07.5,07.0,04.5,07.2	8.0	6.8
	SM83096	3	23.0,13.0,21.0,14.0,11.0, 16.5,22.0,15.0,12.0,11.0	23.0	15.9
83038	SM83097	3	10.0,12.5,11.5,10.0,11.5, 10.0,08.5,09.5,17.0,16.0	17.0	11.7
	SM83098	3	30.0,15.0,23.0,13.0,15.0, 11.0,08.0,11.0,12.0,16.0	30.0	15.4
	SM83099	4	10.3,09.7,10.6,11.3,09.7, 16.0,13.5,15.4,23.3,13.8	23.3	13.4
	SM83100	12	10.0,13.5,11.0,14.8,11.1, 10.8,16.1,12.6,19.8,11.6	19.8	13.1
83039	SM83101	4	13.9,10.8,08.7,07.9,09.4, 14.6,12.3,11.6,09.4,09.6	14.9	10.8
	SM83102	3	23.1,12.5,12.3,18.0,13.3, 15.9,11.8,16.0,12.7,13.2	23.1	14.9
83040	SM83200	4	14.3,10.2,12.1,10.2,12.5, 08.7,09.1,11.3,09.0,10.1	14.3	10.8
	SM83201	3	22.2,13.2,15.5,15.8,18.5,	22.2	16.9

	SM83202	4	17.5,16.1,14.9,16.2,19.5 28.1,14.5,18.4,16.1,16.9, 17.4,12.2,15.2,13.1,15.7	28.1	16.7
	SM83203	3	11.4,11.6,11.0,17.1,13.2 13.6,15.8,20.4,14.3,12.9	20.4	14.1
	SM83204	3	05.9,05.8,07.5,05.2,07.0, 06.7,06.6,06.5,05.3,05.9	7.5	6.2
	SM83184	8	07.8,07.0,08.7,09.1,06.8, 07.8,07.1,10.5,06.5,08.7	10.5	8.0
83041	SM83205	8	06.8,05.5,04.4,04.0,04.8, 04.4,04.5,05.8,04.1,04.6	6.8	4.9
83042	SM83206	11	05.2,05.1,07.3,08.9,05.8, 08.3,05.9,09.5,06.5,08.1	9.5	7.1
	SM83207	4	28.0,18.5,11.0,13.2,10.0, 11.3,09.7,11.8,13.1,12.6	28.0	13.9
	SS83208	4	23.6,16.2,17.9,15.1,18.2, 19.9,10.2,09.4,10.5,10.6	23.6	15.2
83043	SM83209	3	08.8,12.3,13.0,11.6,11.0, 09.0,08.5,10.3,09.2,14.4	14.4	10.8
	SM83210	3	13.0,11.0,09.1,08.3,07.5, 07.0,08.7,09.1,10.8,08.0	13.0	9.3
	SM83211	3	16.0,09.2,08.8,12.3,13.3, 09.7,07.5,06.2,07.7,11.5	16.0	10.2
	SM83212	8	08.7,09.2,05.7,07.8,06.8, 06.5,05.6,04.0,07.7,05.2	9.2	6.7
	SM83213	3	25.0,15.5,14.2,16.0,10.1, 18.0,13.5,17.2,23.0,10.5	25.0	16.3
83044	SM83185	3	30.0,22.0,11.0,24.0,26.0, 15.2,12.5,24.8,13.0,12.0	34.0	20.1
	SM83214	3	12.2,18.3,11.2,07.5,08.1, 09.5,15.0,09.5,10.5,07.8	18.3	11.0
	SM83215	3	15.0,11.0,15.4,14.0,24.0, 17.8,10.5,10.2,09.0,10.2	24.0	13.7
	SM83216	3	11.3,11.1,08.0,14.0,11.5, 08.2,11.2,14.7,11.6,11.7	14.7	11.3
	SM83217	8	13.2,12.0,07.9,16.5,12.1, 08.7,11.0,08.3,07.7,07.6 06.0	16.5	11.1
84011	SM84011	4	15.0,14.0,19.0,14.8,11.8, 20.0,28.2,14.6,13.0,10.1	28.2	16.1
	SM84099	8	12.6,10.0,10.0,20.8,11.7, 13.4,19.4,14.8,09.8,09.0	20.8	13.2
	SM84100	10	02.8,02.4,03.9,03.7,02.7, 02.8,02.1,02.2,02.9,02.3	3.9	2.8
	SM84101	3	09.4,07.2,09.2,07.8,09.6, 10.0,09.8,09.4,08.4,07.4	10.0	8.8
	SM84102	4	13.4,14.0,11.2,10.6,10.4, 11.5,10.0,10.6,09.0,08.6	14.0	11.0
	SM84103	14	07.0,05.7,07.0,06.0,04.5, 04.8,04.6,04.4,03.6,03.6	7.0	5.1

	SM84104	3	14.1,10.0,09.4,08.8,09.0, 07.4,08.2,07.2,05.8,06.0	14.1	8.6
	SM84105	8	10.1,07.0,06.2,04.9,05.4, 04.9,04.5,04.2,04.1,04.2	10.1	5.6
	SM84106	3	06.4,10.3,08.2,08.6,07.2, 09.0,07.2,06.8,05.2,04.8	10.3	7.4
	SM84107	8	09.8,10.0,07.8,05.9,06.0, 06.3,08.6,08.0,08.5,11.6	11.6	8.3
	SM84108	3	14.2,11.6,15.5,11.0,10.6, 12.2,08.2,10.6,09.8,06.9	15.5	11.1
	SM84109	8	11.4,06.4,10.0,10.0,10.4, 08.8,07.8,06.5,08.5,07.4	11.4	8.7
84013	SM84110	2	20.0,25.0,19.0,48.6,46.2, 25.5,23.0,40.1,45.0,44.5	48.6	33.7
	SM84111	2	09.4,08.2,07.1,07.2,05.7, 06.0,05.4,04.8,08.0,05.7	9.4	6.8
	SM84112	2	09.5,06.0,08.9,06.5,06.2, 08.4,06.8,04.8,06.2,05.0	9.5	6.8
	SM84113	2	09.6,06.8,05.8,06.5,06.2, 03.2,03.6,03.2,02.2,03.1	9.6	5.0
	SM84114	14	05.5,06.3,07.3,04.9,03.5, 04.6,06.2,06.6,02.8,02.9	7.3	5.1
	SM84115	2	03.7,03.6,03.5,02.5,03.0, 02.8,02.5,02.7,02.7,02.5	3.7	3.0
	SM84116	2	15.0,20.0,15.0,13.0,13.0, 16.5,23.0,24.0,20.0,15.0	24.0	17.5
	SM84117	2	13.2,06.5,19.0,15.8,10.0, 08.7,09.8,27.0,12.5,36.5	36.5	15.9
	SM84118	2	19.5,13.0,34.5,11.5,11.7, 15.0,13.0,15.0,18.0,13.0	34.5	16.4
	SM84119	1	11.6,05.5,05.2,06.1,03.8, 03.5,04.8,04.1,03.4,04.7	11.6	5.3
	SM84120	2	46.0,23.0,27.0,20.0,39.5, 65.0,25.0,33.0,34.0,20.0	65.0	33.3
	SM84121	2	10.9,09.8,12.0,10.4,10.0, 11.5,07.6,08.0,07.7,07.2	12.0	9.5
	SM84122	2	37.0,44.5,22.5,19.2,29.0, 26.8,16.7,18.5,20.8,18.5	44.5	25.4
	SM84123	2	11.0,06.0,20.8,07.4,08.6, 07.8,06.9,08.0,08.2,08.9	20.8	9.4

B. VECTOR ANALYSIS CALCULATIONS
after Curray (1956) and Royse (1970)

FACIES 3

SECTION NUMBER: 83030

SAMPLE NUMBER: SM83069

CLASS	MID-POINT						
INTERVALS	AZIMUTH (θ)	2θ	sin2θ	cos2θ	n	nsin2θ	ncos2θ
001-010	005	010	0.174	0.985	5	0.868	4.924
011-020	015	030	0.500	0.866	2	1.000	1.732
021-030	025	050	0.766	0.643	7	5.362	4.500
031-040	035	070	0.940	0.342	6	5.638	2.052
041-050	045	090	1.000	0.000	8	8.000	0.000
051-060	055	110	0.940	-0.342	13	12.216	-4.446
061-070	065	130	0.766	-0.643	6	4.596	-3.857
071-080	075	150	0.500	-0.866	7	3.500	-6.062
081-090	085	170	0.174	-0.985	3	0.521	-2.954
091-100	095	190	-0.174	-0.985	4	-0.694	-3.939
101-110	105	210	-0.500	-0.866	5	-2.500	-4.330
111-120	115	230	-0.766	-0.643	4	-3.064	-2.571
121-130	125	250	-0.940	-0.342	7	-6.578	-2.394
131-140	135	270	-1.000	0.000	2	-2.000	0.000
141-150	145	290	-0.940	0.342	5	-4.699	1.710
151-160	155	310	-0.766	0.643	7	-5.362	4.500
161-170	165	330	-0.500	0.866	4	-2.000	3.464
171-180	175	350	-0.174	0.985	5	-0.868	4.924
SUM(S)					100	13.936	-2.748

According to Curray (1956):

$$r = \sqrt{(S \sin 2\theta)^2 + (S \cos 2\theta)^2},$$

where: N-S vector component= $S \cos 2\theta$

E-W vector component= $S \sin 2\theta$

r = magnitude of resultant vector,

n = for grouped data, the number of observations
in each group or class interval,

θ = azimuth from 0°-180° of each observation
or group of observations

S = sum of grouped data

therefore: $S \sin 2\theta = 13.936$

$S \cos 2\theta = -2.748$

$$\text{and } r = \sqrt{(13.936)^2 + (-2.748)^2}$$

$$= \sqrt{201.774}$$

$$= 14.2$$

SECTION NUMBER: 83030 continued

$$L = \frac{r}{S_n} 100$$

where: L = magnitude of resultant vector in terms of percent,

$$\begin{aligned} \text{therefore: } L &= \frac{14.2}{100} 100 \\ &= 14.2\% \end{aligned}$$

$$\theta = \frac{1}{2} \arctan \frac{S_n \sin 2\theta}{S_n \cos 2\theta}$$

where: θ = azimuth of resultant vector,

$$\begin{aligned} \text{therefore: } \theta &= \frac{1}{2} \arctan \frac{13.9363}{-2.7484} \\ &= \frac{1}{2} \arctan -5.071 \\ &= \frac{1}{2} -78.84 \\ &= -39.42^\circ \text{ or } 219.42^\circ \end{aligned}$$

FACIES 3
SECTION NUMBER: 83044
SAMPLE NUMBER: SM83216

CLASS	MID-POINT						
INTERVALS	AZIMUTH	(θ)	2 θ	sin2 θ	cos2 θ	n	nsin2 θ ncos2 θ
001-010	005	010	0.174	0.985	5	0.868	4.924
011-020	015	030	0.500	0.866	3	1.500	2.598
021-030	025	050	0.766	0.643	5	3.830	3.214
031-040	035	070	0.940	0.342	5	4.699	1.710
041-050	045	090	1.000	0.000	9	9.000	0.000
051-060	055	110	0.940	-0.342	3	2.819	-1.026
061-070	065	130	0.766	-0.643	12	9.192	-7.714
071-080	075	150	0.500	-0.866	3	1.500	-2.598
081-090	085	170	0.174	-0.985	4	0.694	-3.939
091-100	095	190	-0.174	-0.985	4	-0.694	-3.939
101-110	105	210	-0.500	-0.866	6	-3.000	-5.196
111-120	115	230	-0.766	-0.643	5	-3.830	-3.214
121-130	125	250	-0.940	-0.342	7	-6.578	-2.394
131-140	135	270	-1.000	0.000	2	-2.000	0.000
141-150	145	290	-0.940	0.342	6	-5.638	2.052
151-160	155	310	-0.766	0.643	7	-5.362	4.500
161-170	165	330	-0.500	0.866	8	-4.000	6.928
171-180	175	350	-0.174	0.985	6	-1.042	5.909
SUM(S)						100	1.958 1.814

According to Curaray (1956):

$$r = \sqrt{(Snsin2\theta)^2 + (Sncos2\theta)^2},$$

where: N-S vector component= Sncos2 θ
E-W vector component= Snsin2 θ
r= magnitude of resultant vector,
n= for grouped data, the number of observations
in each group or class interval,
0= azimuth from 0°-180° of each observation,
or group of observations,
S= sum of grouped data

therefore: Snsin2 θ =1.958
Sncos2 θ =1.814

$$\begin{aligned} \text{and } r &= \sqrt{(1.958)^2 + (1.814)^2} \\ &= \sqrt{7.125} \\ &= 2.7 \end{aligned}$$

SECTION NUMBER: 83044 continued

$$L = \frac{r}{S_n} 100.$$

where: L = magnitude of resultant vector in terms of percent

$$\begin{aligned} \text{therefore: } L &= \frac{2.7}{100} 100 \\ &= 2.7\% \end{aligned}$$

$$\theta = \frac{1}{2} \arctan \frac{S_n \sin 2\theta}{S_n \cos 2\theta}$$

where: θ = azimuth of resultant vector,

$$\begin{aligned} \text{therefore: } \theta &= \frac{1}{2} \arctan \frac{1.958}{1.814} \\ &= \frac{1}{2} \arctan 1.079 \\ &= \frac{1}{2} 47.2 \\ &= 23.6^\circ \end{aligned}$$

C. MEASURED SECTIONS AND COLUMNS: TRAIL HILL, LOVETT
HILL, SOURDOUGH HILL (FOLD-OUT).